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Exploration, Explanation, and Parent–Child Interaction in Museums

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Abstract

Young children develop causal knowledge through everyday family conversations and activities. Children's museums are an informative setting for studying the social context of causal learning because family members engage together in everyday scientific thinking as they play in museums. In this multisite collaborative project, we investigate children's developing causal thinking in the context of family interaction at museum exhibits. We focus on *explaining* and *exploring* as two fundamental collaborative processes in parent–child interaction, investigating how families explain and explore in open-ended collaboration at gear exhibits in three children's museums in Providence, RI, San Jose, CA, and Austin, TX. Our main research questions examined (a) how open-ended family exploration and explanation relate to one another to form a dynamic for

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children's learning; (b) how that dynamic differs for families using different interaction styles, and relates to contextual factors such as families' science background, and (c) how that dynamic predicts children's independent causal thinking when given more structured tasks. We summarize findings on exploring, explaining, and parent–child interaction (PCI) styles. We then present findings on how these measures related to one another, and finally how that dynamic predicts children's causal thinking.

In studying children's exploring we described two types of behaviors of importance for causal thinking: (a) *Systematic Exploration*: Connecting gears to form a gear machine followed by spinning the gear machine. (b) *Resolute Behavior*: Problem-solving behaviors, in which children attempted to connect or spin a particular set of gears, hit an obstacle, and then persisted to succeed (as opposed to moving on to another behavior). Older children engaged in both behaviors more than younger children, and the proportion of these behaviors were correlated with one another.

Parents and children talked to each other while interacting with the exhibits. We coded causal language, as well as other types of utterances. Parents' causal language predicted children's causal language, independent of age. The proportion of parents' causal language also predicted the proportion of children's systematic exploration. Resolute behavior on the part of children did not correlate with parents' causal language, but did correlate with children's own talk about actions and the exhibit.

We next considered who set goals for the play in a more holistic measure of parent–child interaction style, identifying dyads as parent-directed, child-directed, or jointly-directed in their interaction with one another. Children in different parent–child interaction styles engaged in different amounts of systematic exploration and had parents who engaged in different amounts of causal language. Resolute behavior and the language related to children engaging in such troubleshooting, seemed more consistent across the three parent–child interaction styles.

Using general linear mixed modeling, we considered relations within sequences of action and talk. We found that the timing of parents' causal language was crucial to whether children engaged in systematic exploration. Parents' causal talk was a predictor of children's systematic exploration only if it occurred prior to the act of spinning the gears (while children were building gear machines). We did not observe an effect of causal language when it occurred concurrently with or after children's spinning. Similarly, children's talk about their actions and the exhibit predicted their resolute behavior, but only when the talk occurred while the child was encountering the problem. No effects were found for models where the talk happened concurrently or after resolving the problem.

Finally, we considered how explaining and exploring related to children's causal thinking. We analyzed measures of children's causal thinking about gears and a free play measure with a novel set of gears. Principal component analysis revealed a latent factor of causal thinking in these measures. Structural equation modeling examined how parents' background in science related to children's systematic exploration, parents' causal language, and parent–child interaction style, and then how those factors predicted children's causal thinking. In a full model, with children's age and gender included, children's systematic exploration related to children's causal thinking.

Overall, these data demonstrate that children's systematic exploration and parents' causal explanation are best studied in relation to one another, because both contributed to children's

learning while playing at a museum exhibit. Children engaged in systematic exploration, which supported their causal thinking. Parents' causal talk supported children's exploration when it was presented at certain times during the interaction. In contrast, children's persistence in problem solving was less sensitive to parents' talk or interaction style, and more related to children's own language, which may act as a form of self-explanation. We discuss the findings in light of ongoing approaches to promote the benefit of parent–child interaction during play for children's learning and problem solving. We also examine the implications of these findings for formal and informal learning settings, and for theoretical integration of constructivist and sociocultural approaches in the study of children's causal thinking.

I. Theoretical Background and Research Questions

Children learn about the causal structure of the world by exploring and explaining. They discover causal relations, mechanisms, and outcomes through interacting with their environment (e.g., Schulz & Bonawitz, 2007; Van Schijndel, Franse, & Raijmakers, 2010) and through conversation with parents, teachers, and peers (e.g., Callanan & Oakes, 1992; Chouinard, 2007; Corriveau & Kurkul, 2014; Frazier, Gelman, & Wellman, 2009). We argue that the processes of explaining and exploring are dynamic and collaborative (Legare, Sobel, & Callanan, 2017). Children can learn from solitary interaction with the world and from self-explanation and reflection, but they also learn through collaborative interaction with others—by watching others' actions, by communicating their ideas, by co-constructing explanations, and by participating in joint problem solving with other people. In this monograph, we focus on how children play within parent–child interaction and how that play relates to children's learning.

The objective of this monograph is to examine exploratory play and family conversation (particularly focused on causal explanation) during parent–child interaction in children's museums, and the relation between such behaviors and children's causal thinking. Parent–child interaction can be studied in many contexts. We chose to focus on parent–child interaction in an informal learning setting—open-ended gear exhibits in three children's museums. Children's museums can be an ideal setting for studying the social context of the development of causal thinking, at least for some families. Children's museums have a genuine commitment to understanding how children learn and how best to support children's learning; they offer a context that encourages open-ended exploration and parent–child interaction to foster children's cognitive, social, and emotional development. Given this context, research in museums can offer a glimpse into families' everyday interactions in structured and unstructured settings that may include opportunities for learning. In addition, museum practitioners provide support for both children and caregivers by creating opportunities for families to play together, and by modeling ways of supporting children's learning through play. For these reasons, even though museums are not everyday settings for all families, research on adult–child interactions in these settings can inform educational practices not only in museums, but also in other early childhood settings that often incorporate play and exploration as avenues for learning. Further, collaboration between university researchers and museum practitioners helps each group inform the other to gain a better understanding of how children's learning unfolds (Callanan, 2012; Sobel & Jipson, 2016).

Why Exploring and Explaining?

Exploration and explanation are collaborative processes, yet are often studied independently. We will first consider research on children's exploration, which has produced exciting findings, yet often fails to consider how children generate explanations or learn from others' explanations. We will next consider research on how children use their own and others' explanations for learning, from which valuable insights have emerged, but that rarely considers exploratory play as part of the learning process. Much of the previous research on children's exploration and explanation comes from a constructivist perspective, which focally examines the internal process of constructing causal representations of the world from external input (Gopnik, Meltzoff, & Kuhl, 1999; Gopnik & Wellman, 1994; Wellman & Gelman, 1998). By exploring the social context of exploring and explaining, we seek to expand that focus, as we discuss further below.

Despite the fact that explanation and exploration have been studied independently, recent research provides compelling evidence that the two processes are not mutually exclusive, but instead are often intertwined in complex ways. Children's exploration often leads them to seek and find explanations (Bonawitz, van Schijndel, Friel, & Schulz, 2012; Legare, 2012; Mills, Legare, Bills, & Mejias, 2010). Similarly, explanatory talk often leads to further exploration (Willard et al., 2019). Here we seek to document the complex dynamics between explanation and exploration in the context of parent–child interaction.

Isolating explanation and exploration from each other in the context of early causal learning research often creates a false dichotomy. For example, the contrast between explaining and exploring is reminiscent of the distinction made between instruction and discovery, which is often presented as a dichotomy (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011). Recent research on pedagogy and guided play has reignited questions about the relative roles of adult guidance versus child-directed exploration in the learning process (Weisberg, Hirsh-Pasek, Golinkoff, Kittredge, & Klahr, 2016). Researchers and practitioners frequently ask questions such as: Do children learn best when they explore the world on their own, or when adults provide direct instruction? (Klahr, 2000; Klahr & Nigam, 2004; Kuhn, 1989; Kuhn & Dean, 2005). More recently, the hybrid notion of guided play has been offered as a strategy for balancing the two approaches (Mayer, 2004; Weisberg, Hirsh-Pasek, & Golinkoff, 2013). In addition, informal learning environments like children's museums are often designed to support both children's active exploration and their social interaction with caregivers and peers, recognizing both as critical aspects of learning and development (Gutwill & Allen, 2010).

Instruction, guidance, and discovery all play important roles in the learning process. Their contributions depend on the individual learners involved and on the activity that they are engaged in together. In addition, adults' involvement in children's learning is shaped by many factors, including cultural norms, family dynamics, and personal preferences (Gaskins & Paradise, 2010). There is also cultural variability in whether direct instruction or child-directed language are considered appropriate ways to interact with young children (Heath, 1983; Ochs, 1988; Rogoff, 2003). Given that communities vary in the value they place on adult-directed scaffolding of child activity (Lancy, 2016), it is important to ask what other learning processes we may be missing because of culturally-specific assumptions. In the present work, we seek to examine how explanation and exploration interact in everyday interactions between parents and their children, without a priori expectations for how best to optimize learning outcomes.

Our research is motivated by our interest in integrating constructivist theories of children's causal learning with sociocultural theories of parent–child interaction. To give this theoretical endeavor empirical traction, we recorded parent–child interaction at three gear exhibits in three children's museums across the United States. Our participants represent diverse families who visit children's museums and science centers. We coded how children explored the exhibit, and how parents and children used language—particularly causal explanatory language—to communicate with each other. Moreover, we documented styles of parent–child interaction, focused particularly on how goals for the interaction were set, and asked whether patterns of explanation and exploration differed among these interactive styles. We investigated the relations among these behaviors across the whole interaction, but also within the dynamics of minute-by-minute interaction. We examined how hearing causal explanations at particular moments in time impacted the likelihood of children engaging in particular exploratory behaviors. Finally, children responded to a set of follow-up causal learning measures, some of which examined their memory of the gear system and their causal understanding of gear mechanisms, and some of which examined their ability to generalize their causal knowledge to a different set of gears. Our goal here was to document relations between the exploration and explanation children engaged in with a parent, and children's demonstration of causal knowledge about gears independently.

Both constructivist and sociocultural theorists concur that young children's causal thinking develops within the context of everyday activity and conversation. In this introductory chapter, we first consider the theoretical background that motivated the present study, arguing that an integration of constructivist and sociocultural theories provides a powerful and generative context for examining the development of children's causal thinking. Next, we discuss previous research on exploring, then on explaining, in both cases considering how these processes relate to children's cognitive development. Finally, we introduce the more detailed research questions that motivate our study.

Integrating Constructivist and Sociocultural Theories

Understanding social contexts of children's learning has been central to all theories of cognitive development, yet different theories make different assumptions about the mechanisms of development. Whereas constructivist theories, beginning with Piaget, acknowledge the important role of experience in children's learning, they nevertheless consider the internal workings of the child's mind to be the locus of development (Miller, 2011). In contrast, sociocultural theories, beginning with Vygotsky, emphasize the social context as the setting where development takes place (Callanan & Valle, 2008; Daniels, 2011; Rogoff, 2003).

Constructivist and sociocultural theories also differ regarding the unit of analysis under study, the locus of developmental change, and the goals of development. Constructivist theory compares children to little scientists who are motivated to acquire concepts and construct theories about the world around them (Gopnik et al., 1999; Gopnik & Wellman, 1994; Wellman & Gelman, 1998). The individual child is the unit of analysis, and development is assumed to happen within the child's mind. Social influences on cognition are often discussed in terms of input, instruction, or "transmission" of information (Miller, 2011). In contrast, sociocultural theory compares children to little anthropologists with the goal of making sense of the world in order to participate with others in their community (Gaskins & Paradise, 2010; Legare & Harris, 2016). Rather than considering children's learning as a process of individual processing of information, learning is seen as embedded in children's active engagement in social activities and practices (Cole, 1996, 2010; Daniels, 2011; Gauvain & Perez, 2015; Rogoff, 2003; Vygotsky, 1962). Moreover, instead of analyzing development within individual children's minds, the social group is seen as the unit of analysis where development occurs. Development happens through the dynamics of social interactions rather than in the privacy of children's minds.

As Flavell (1996) argued, researchers in cognitive development often take for granted Piaget's notion of children's active role in constructing new knowledge. Recent theories of rational constructivism focus considerable attention on the impact of diverse experiences and events on the development of cognition (Gopnik & Wellman, 2012; Sobel & Kushnir, 2013; Xu & Kushnir, 2012). Constructivist theories continue to characterize social experiences as input to learning mechanisms. Doing so implies that social interaction is secondary to the development that is located within children's minds. That is, social interaction is merely another form of information, which is processed by children via a more central learning mechanism; children can do what they choose with that social information.

In contrast, sociocultural theory eschews the belief that social interaction is just another form of data and that one can add the variable of culture or social experience as part of a universal model of development. Instead, sociocultural theory emphasizes a much more dynamic and co-constructed understanding of the world; culture is not a variable because learning is inherently dialectical (Daniels, 2011). In other words, cognition is shaped by social experience, and mediated by cultural artifacts and interactions, and at the same time cognition produces and modifies those tools and interactions (Cole, 1996). Daniels (2011) describes Vygotsky's conception of mind as "a mediated process in which culturally produced artifacts…shape and are shaped by human engagement with the world" (p. 673). Importantly, the focus of sociocultural research is on children's everyday social experiences, which requires recognition that these experiences vary for children living in different communities and cultures (Rogoff, Dahl, & Callanan, 2018). Consistent with recent critiques that psychological research has focused too narrowly on WEIRD (Western, Educated, Industrialized, Rich, Democratic) populations (Henrich, Heine, & Norenzayan, 2010; Nielsen, Haun, Kärtner, & Legare, 2017), sociocultural theory emphasizes that cultural contexts must be considered as part of the interpretation of any developmental process or outcome (Rogoff, 2003).

Rather than examining the development of causal learning from constructivist and sociocultural lenses independently, we aim to integrate the two in order to create a more comprehensive approach to the study of cognitive development in context (Legare et al., 2017). While constructivist approaches provide a valuable perspective regarding how children create meaning from information, they tend to reduce social context to input. While sociocultural approaches emphasize complexity of social interaction, and treat it as a context for development, they leave unanalyzed the ways that children take information they learn with them as they move on to new contexts. Some would argue that constructivist and sociocultural accounts are incompatible, but in the spirit of Cobb's (1994) comment that each theory "tells half of a good story" (p. 17), one goal in this monograph is to explore the possibility that the two can be integrated into one theoretical approach (see also Greeno, 1997; Packer & Goicoechea, 2010). We aim to consider how the socially constructed meaning-making of sociocultural theories can be integrated with the individually mediated meaning-making of constructivist theories.

The synthesis of constructivist and sociocultural approaches begins with a synthesis of distinct methodological approaches. Our strategy is to conduct microanalysis of the dynamics of children's and parents' spontaneous conversation and activity, and to link those methods with more traditional cognitive developmental tasks. We seek to work toward developing a novel integrative approach by focusing on the dynamic interplay between children and parents in play to uncover predictors of children's learning processes. We will return to the notion of theory integration in Chapter VIII. As background for our study, in the next sections, we review research on the roles of exploration and explanation in children's developing causal thinking.

Exploratory Play and Causal Thinking

We define *exploration* as actions children make that can generate information from others or the environment. Children's behavior has often been used as a measure of their causal knowledge. As one example, Gopnik, Sobel, Schulz, and Glymour (2001) used evidence that 3- and 4-year-olds can effectively intervene on a causal structure as a measure of their understanding of the conditional independence among events that signifies causal relations (following Pearl, 2000). They introduced children to a novel machine that lit up and played music when certain objects were placed on it (*a blicket detector*). Children were shown that some objects made the machine go, but others did not (objects A and B). Object A was placed on the machine, which did not make the machine activate. Object A was removed, and object B was placed on the machine. The machine activated while object B was on it. Object A was then placed on the machine again, with object B. Children were told to make the machine stop. Most children took only object B off the machine, as opposed to returning the machine to its original (empty) starting state. Their actions on the causal system provided evidence of their understanding of the causal relations among the objects and the machine (see also Sobel & Kirkham, 2006; Sobel, Tenenbaum, & Gopnik, 2004, for other examples of children's actions indicating their causal knowledge).

Children learn about causal systems through active exploration. For example, Schulz, Gopnik, and Glymour (2007) examined how children learn by acting on a novel causal system. They introduced 4–5-year-olds to a gear machine with two removable gears; children had to learn which gear caused the other to move. Children could intervene on the system by turning it on and off, and by removing each gear, so they could see whether each functioned independently of the other. They found that children who tested the gears individually to reveal conditional independence among them were more likely to report the causal structure that they learned.

The relation between children’s exploration and learning is supported by laboratory-based research, which suggests children learn more through their own exploratory actions than through observing others generate the same data (Baldwin, Markman, & Melartin, 1993; Bonawitz et al., 2012; Gerson & Woodward, 2014; Kushnir & Gopnik, 2005; Needham, 2009). The benefits of learning from one’s own actions are most prominent when children discover novel information (McCormack, Bramley, Frosch, Patrick, & Lagnado, 2016; Sobel & Sommerville, 2010; Sommerville, Woodward, & Needham, 2005). Children might benefit more from discovering information themselves because they understand the intentions behind their own actions, and thus recognize the reasons behind why they are seeking out new information. In support of this hypothesis, when given appropriate rationales for others’ actions, preschoolers were able to learn more effectively from those actions (Sobel & Sommerville, 2009).

In real-world learning environments, exploration also allows children to satisfy their curiosity (Loewenstein, 1994). Jirout and Klahr (2012), for example, argue that curiosity “relates to information-seeking behaviors, such as those that are observed in learning environments” (p. 127). They suggest that the act of exploring is related to children’s desire to fill gaps in their knowledge. Moreover, this motivation to explore is self-propagating. As children explore their world, they uncover surprising events, and they further explore to seek out greater understanding. For example, Schulz and Bonawitz (2007) found that preschool-aged children explored a novel toy more systematically when they had encountered ambiguous evidence about how the toy worked. Children explored for longer periods of time when given incomplete evidence (Bonawitz et al., 2012; Jara-Ettinger, Gweon, Tenenbaum, & Schulz, 2015) or when faced with events that were related stochastically as opposed to deterministically (Cook, Goodman, & Schulz, 2011). Even infants engaged in more exploration when shown surprising events (Stahl & Feigenson, 2015). Legare (2012) found that when young children’s exploration led to unsuccessful or unexpected outcomes, they generated new hypotheses, which led to further exploration. Exploring is a way for children to make sense of their own experiences, to collect further evidence, and to test hypotheses.

Evidence of sophisticated and precocious abilities to learn through self-directed exploration stands in contrast to a large literature in educational psychology on scientific reasoning, which suggests that children struggle with certain fundamental capacities in learning from their own actions. For example, children (and in many cases, adults) have difficulty designing informative, controlled interventions to isolate causal relations (i.e., engaging in the “control of variables” strategy, see Chen & Klahr, 1999). Moreover, children often fail to anticipate the type of evidence that would support or undermine a causal hypothesis (Dean & Kuhn, 2007; Klahr, 2000; Masnick & Klahr, 2003). In studies of this kind, scientific reasoning is typically presented as part of broader learning goals—for example, to learn about earthquakes in a science lesson (Kuhn & Dean, 2005), or to learn about springs and force dynamics (Schauble, 1996). The addition of complex content knowledge may introduce demand characteristics and potentially interfere with children's reasoning abilities. Moreover, this additional background information might not be engaging to children, thus perhaps reducing their motivation to explore.

In classroom settings, students who discover information for themselves are more motivated to achieve educational goals and more likely to remember information they have learned (Bruner, 1961; Renninger & Wozniak, 1985). Students learn more effectively by discovering causal structure through guided activity-based exercises, rather than being directly told what to do, or being given unstructured activity (Bredderman, 1983; Kittel, 1957; Lehrer & Schauble, 2012; Shulman & Keislar, 1966). Self-generated action can assist even in more formal scientific reasoning, where both children and adults might struggle (Kuhn & Ho, 1980).

The focus of the current research is not formal classroom science education, but everyday interactions in informal learning environments, such as museums. In these spaces, the ways that children explore can be influenced in subtle ways by the actions of other people and by how children understand others' goals (Fung & Callanan, 2013). As one example, in a study of parent–child engagement at a museum exhibit (a zoetrope), Crowley et al. (2001) found that when parents were present, children were more likely to engage in exploration of all of the relevant components of the exhibit. Parents also guide children's exploration in subtle ways that are likely to lead to better understanding of the phenomenon (Fender & Crowley, 2007). These findings are relevant to more recent research showing that guided play can lead to better learning than open-ended play, when goals involve content-based learning outcomes (Weisberg et al., 2013).

As another example, Van Schijndel et al. (2010) showed that parents can be instructed to scaffold their children's exploratory behaviors, and brief interventions on the part of museums could be used to support parents in supporting their children's exploration. Similarly, Willard et al. (2019) gave parents minimal interventions using conversation cards which suggested that they encourage their children to explore a gear exhibit. Children encouraged by their parents to explore spent more time making connections among gears and building more complex machines compared to baseline interaction.

In more naturalistic observation of parent–child exploration, exploring with social partners takes different forms for different children, and is not based exclusively on children's internal learning mechanisms, but also based on family dynamics, gender-related expectations, and cultural practices (Rogoff, Paradise, Mejia Arauz, Correa-Chavez, & Angelillo, 2003). In some families and communities, collaborative exploration can be fluid and collaborative, while in others, it may look more like parallel but independent action (Rogoff et al., 2017). Mutual exploration can also vary in the extent to which it entails resolving tension when children and parents have different goals during an interaction. Within the range of activities that have been described as "guided play" are cases of adults setting goals for children to pursue, directing children about how to explore, supporting children in setting goals for themselves, or helping them work toward those goals.

The expectation that children learn through active exploration, and should be given the opportunity to do so, is common across diverse populations (Lancy, 2016; Rogoff et al., 2017). For example, Inuit “parents do not presume to teach their children what they can as easily learn on their own” (Guemple, 1979, p. 50). Okinawan parents “put relatively few restrictions on their children’s time, which they believe allows them to learn about daily activities” (Maretzki & Maretzki, 1963, p. 514). In the ethnographic literature, there is a long-standing belief that children are motivated to learn culturally relevant skills as a way of showing support for their family and becoming a member of their community (Gaskins & Paradise, 2010). What is often different about exploratory practices across cultures is the ex tent to which parents offer guidance or are involved in children’s exploration for learning (Lancy, 2016). While our study is not cross-national, we are attentive to cultural variation and individual differences in the ways in which parents are involved in children’s exploratory practices. We examine parents’ and children’s spontaneous interaction, both in terms of children’s exploration of an exhibit, and in terms of who sets goals at the exhibit.

Gender-related expectations also figure in children’s opportunities for exploratory learning, especially in the STEM domains. Boys and girls tend to play with different types of toys, and parents tend to provide gender-stereotyped toys and activities to their children (e.g., Fulcher & Coyle, 2018; Martin, Eisenbud, & Rose, 1995). Gender-stereotyped toys provided different types of affordances for children’s exploratory play, with building and block toys allowing for engineering-related exploration, while doll play invites exploration through pretend play and social interaction. In a recent study, Coyle and Liben (2018) tested a gendered building toy marketed to girls (GoldieBlox) and compared it to a version they created that was named to suggest that it was a stereotypical boys’ toy (BobbyBlox). They found evidence that marketing changed children’s learning. In particular, girls learned a mechanical belt-drive concept better with BobbyBlox, but boys learned the concept better with GoldieBlox. While the specific result was unexpected, the important finding is that gendered packaging and naming of toys may have impact on children’s learning. Because girls and boys may have different experiences with exploratory play, it is important for us to consider whether there are gender differences in our measures of exploration.

Explanatory Conversation and Causal Thinking

Classic research on children’s causal thinking investigated the ways in which children interpreted events they directly observed (Bullock, Gelman, & Baillargeon, 1982; Shultz & Mendelson, 1975; Siegler, 1976). From the perspective of philosophy of science, these studies focused on children’s beliefs about how events were related to one another, as opposed to the actual ways the events were related. For example, much of the laboratory-based research in the previous section presents children with novel causal structures (like the blicket detector) to test their interpretation of the situation—their beliefs about how events are related (e.g., object B will make the detector activate)—and not their explanations of how or why those events occurred (what makes the machine activate).

Explanations focus on children’s understanding of the ontology of the world. For the purposes of this monograph, we will define *explanation* as the ways in which individuals elicit and generate verbal information about causal relations. To study explanation, researchers in cognitive development have taken one of two approaches, one more constructivist and the other more sociocultural in nature. The first is to interpret explanations as reflecting children's real-world causal knowledge (Hickling & Wellman, 2001; Keil & Wilson, 2000; Legare, Wellman, & Gelman, 2009; Mills & Keil, 2004; Piaget, 1929, 1930; Sobel, 2004; Wellman & Liu, 2007). For example, Schult and Wellman (1997) used the way children generated explanations of human action to illustrate their domain-specific causal knowledge about intentionality (see also Wellman, Hickling, & Schult, 1997). The second approach is to consider explanation as an activity that plays a role in constructing new understandings. In this way, explanation is not only a window on children's causal thinking, but is also a social mechanism by which children learn new information, develop causal understanding, and learn how to talk about their knowledge (Alvarez & Booth, 2014; Hood, Fiess, & Aron, 1982; Walker, Lombrozo, Williams, Rafferty, & Gopnik, 2017). In line with our attempt to synthesize theoretical perspectives, we considered both aspects of explanation in designing our coding and analysis.

If explanation is a mechanism for constructing new understanding, learners should explain the observations that have the greatest potential to teach them something novel; namely, those that are inconsistent with respect to their current knowledge. Legare and colleagues have shown that outcomes inconsistent with prior knowledge are most likely to trigger children's explanations (Legare, 2012; Legare & Gelman, 2014; Legare, Gelman, & Wellman, 2010), suggesting that explanation can provide children with the opportunity to revise hypotheses based on new evidence (Busch & Legare, 2019). Encouraging children to explain inconsistency may serve as a mechanism for integrating and reconciling discordant or ambiguous information with existing theories. Related to this idea, generating explanations also helps children to interpret their observations and acquire new information (Bonawitz et al., 2012; Chi, De Leeuw, Chiu, & LaVancher, 1994; Crowley & Siegler, 1999; Legare & Lombrozo, 2014; Macris & Sobel, 2017; Walker et al., 2017). Explaining can improve children's reasoning even if the explanations that are generated are not correct (Lombrozo, 2016). These lines of research all suggest that the explanations children generate reflect their causal knowledge and may function as a learning mechanism (Wellman, 2011).

The desire for explanations reflects children possessing (and potentially understanding that they possess) a gap in their knowledge. This desire also reflects children's drive to understand the world around them (Brewer, Chinn, & Samarapungavan, 1998; Gopnik, 1998). For example, children seek out information from others and the efficiency and efficacy of their questions increases with age (Legare, Mills, Souza, Plummer, & Yasskin, 2012; Mills, Legare, Grant, & Landrum, 2011; Ruggeri & Lombrozo, 2015; Ruggeri, Lombrozo, Griffiths, & Xu, 2016). The motivation to ask for explanations from others might also reflect children's drive for social interaction and desire to share knowledge. Explaining is a social and communicative act for children, particularly in their everyday lives (Callanan, Shrager, & Moore, 1995; Hood et al., 1982). Whether requesting, hearing, or helping to construct ex planations, children learn in these conversations, both about the causal structure of their world, and about what counts as an explanation in their family and community.

Research on children's "why" questions confirms that children look to others to request explanations and use them to better understand causal mechanisms. In early research by

Hood and Bloom (1979), the eight 30-month-olds they studied were productively using causal statements and "why" questions, suggesting that these abilities emerge early in the preschool years. In a diary study, Callanan and Oakes (1992) similarly found that parents of 3–5-year-olds reported their children's spontaneous use of meaningful "why" questions in conversation. Frazier et al. (2009) provided clear evidence that these questions are likely to be true requests for causal explanations rather than merely bids to keep conversation going. Children were more likely to ask versions of the same question when given a non-explanatory reply, but were more likely to ask a new follow-up question when given an explanatory answer. These findings suggest that children's "why" questions can be seen as a way to seek out information from more experienced members of their family and/or community.

In addition to their use of "why" questions, children request information from others during collaborative activities (Bjorklund, Hubertz, & Reubens, 2004; Callanan, Siegel, & Luce, 2007; Harris & Koenig, 2006; Lancy, 2008; Lave & Wenger, 1991). The distinction between children's own actions and goals and the actions and goals of others is blurred when collaborating (Bjorklund, 1997; Sommerville & Hammond, 2007). Explaining to others and requesting explanations from others are inherently collaborative acts that give children the opportunity to take on the goals and potential knowledge states of others.

Consider the self-explanation effect—the idea that generating explanations influences learning. The origins of this effect come from the literature on formal problem solving (Chi, Bassok, Lewis, Reimann, & Glasser, 1989; Chi et al., 1994), and in the context of this research, explanations could be generated for the self or for a communicative partner. For example, Rittle-Johnson, Saylor, and Swygert (2008) found that children's generalization during problem solving was superior when they generated explanations for their mothers, in contrast to themselves. This research suggests that at least in WEIRD populations, there are potential differences in how knowledge is constructed for the self, versus with a social partner. Such differences may relate to natural pedagogy, or early-developing cognitive biases to attend to communicative intent (Csibra & Gergely, 2006, 2009). Moreover, such differences suggest that children are evaluating others as sources of knowledge both for novel information (Harris, Koenig, Corriveau, & Jaswal, 2018; Mills, 2013; Sobel & Kushnir, 2013), and also metacognitively for their quality as a teacher (Gweon, Peyton, Konopka, & Schulz, 2014).

In a parallel, but distinct research literature, explanatory talk is seen as a social practice, particularly in considering how parents talk to children. For example, Haden (2010) has characterized elaborativeness in parents' talk in informal learning settings, borrowing from previous research on parent–child reminiscence (Fivush, Haden, & Reese, 2006). Parents who are encouraged to use more elaborative talk about science in informal settings, including generating explanations and asking open-ended questions, have children who seem to be more engaged with play at the exhibit and who remember more from their museum experience at a later date (Benjamin, Haden, & Wilkerson, 2010; Haden et al., 2014; Jant, Haden, Uttal, & Babcock, 2014). Similarly, Willard et al. (2019) found that when parents were given conversation cards suggesting that they encourage their children to generate explanations in a gear exhibit, they were more likely to talk about causal mechanisms of the gears. In addition, the frequency of parents' explanatory questions predicted children's testing of gear machines and time spent building their own machines in a follow-up task.

Research on museums and informal learning environments that focus on families' spontaneous styles of conversation have also highlighted explanatory talk as potentially important for children's developing STEM learning. Parents' explanations frame experiences and activities for children in ways that may help children achieve deeper understanding (e.g., Crowley, Callanan, Tenenbaum, & Allen, 2001; Tare, French, Frazier, Diamond, & Evans, 2011). Fender and Crowley (2007) found that children whose parents explained a museum exhibit to them were more likely to develop a conceptual understanding of the exhibit compared to children whose parents did not provide any explanation. Parents also have unique expertise regarding their children's previous experiences and interests, and some evidence suggests that parents' talk about these personal connections may be more important for children's engagement and understanding than parents' scientific explanatory talk (Callanan, Castañeda, Luce, & Martin, 2017).

There is substantial cultural variation in the extent to which children are encouraged to solicit explanations from others and to generate explanations to others. For example, ethnographic studies in Kpelle-speaking West Africa, Borneo, and rural Guatemala report that children are not encouraged to ask questions or seek explanations from caregivers; instead, there is a strong cultural expectation to learn through observation (Lancy, 1996; Nicolaisen, 1988; Rogoff, 2003). Similarly, children in Inuit cultures are expected to listen to others' conversations, but are discouraged from asking questions of adults (Crago, 1992; Lancy, 2016). Gauvain, Munroe, and Beebe (2013) found cultural differences in the frequency of children's causal questions when comparing archival data from non-Western communities to existing data from middle-class U.S. families. These findings shed doubt on the idea that there are specific innate mechanisms for learning from others. Instead, they suggest that such learning is influenced by the nature of the shared cultural practices in children's communities. Even if we are born prepared to learn from others, how that learning happens is a function of the dynamics of the cultural context.

There is also substantial cultural variation in family explanatory talk. Differences in types of causal talk have been uncovered when comparing parents with varied schooling background, income levels, or attitudes about the nature of knowledge (Kurkul & Corriveau, 2018; Luce, Callanan, & Smilovic, 2013; Valle, 2006). For example, Valle (2006) found that highly educated U.S. parents from engineering and science backgrounds focused more on scientific evidence about conflicting claims on topics such as climate change than did parents from other educational backgrounds. In cross-cultural investigations, parents from the United States talked to their children more and asked their children more questions than did parents from Vanuatu (Clegg et al., 2019). It is important, however, to use caution when generalizing findings from one cultural context to another, and to recognize that cultural norms regarding explanatory talk are part of what children learn by engaging in everyday activities with parents and other family members.

Gender-related differences are also apparent in family conversations about STEM-related topics. Crowley et al. (2001) found that parents used explanations more often in a children's museum when talking to their preschool-aged sons than to their daughters. This was true despite there being no gender differences in children's questions or in measures of their interest in the exhibits. In a study with older children (11- to 13-year-olds), Tenenbaum and Leaper (2003) found that parents believed science was more difficult and less interesting for their daughters than for their sons, despite the fact that there were no gender differences in children's science grades or expressed interest in science. Also, in the Coyle and Liben (2018) article discussed earlier, parents talked differently to girls and boys about the STEM-related toys, focusing more on reading the narrative instructions with girls and on building with boys. As with exploring, previous research on explaining in parent–child conversation makes clear that children's gender is an important variable to consider in our analyses.

In sum, how parents and children spontaneously communicate with one another reflects a distinction made at the start of this section—between explanation and interpretation. Parents generate their own interpretations of many events—their beliefs about causal relations. Children potentially treat those interpretations as explanations—or even as facts about the world. How parents explain to children potentially influences how children understand causal relations. There is cultural variation in parent–child interaction and communicative styles. How parents generate language during spontaneous play with children might affect how children act during play and learn from those actions. This process may also be mediated by the way in which children understand play to involve (or not involve) their parents. To consider these issues, in our studies, we consider not only what parents and children say—in terms of the causal knowledge that is explained by parents or information requested by children during free play—but also the way in which parents and children construct the goals over the course of their interaction.

Families Explaining and Exploring in Informal Settings

Whereas both exploring and explaining have been independently linked to children's causal thinking, less attention has been paid to the integration of these two processes in children's learning. Research that suggests that young children have sophisticated capacities to both explain and explore comes primarily from controlled laboratory-based studies. The extent to which these capacities translate to formal or informal learning environments is understudied, even though social contexts can have a profound impact on children's behavior and learning. The informal learning environments of children's museums provide an ideal setting for research on the interaction between exploration and explanation (Allen, 2004; Callanan, 2012; Crowley & Knutson, 2005; Gutwill & Allen, 2010; Haden, 2010). Because children's museums are designed to promote exploration (Gaskins, 2008a) and parent–child conversations (Callanan & Jipson, 2001; Callanan et al., 2012), research in informal learning environments allows scientists to study the interaction between children's cognition and the social context of family interactions and conversations (Benjamin et al., 2010; Callanan & Jipson, 2001; Gaskins, 2008a, 2008b; Sobel & Jipson, 2016). Museums also provide opportunities to investigate diversity in children's social learning experiences, providing information needed to advance our understanding of how to broaden participation in science learning (Tenenbaum & Callanan, 2008).

Finally, how families explain and explore together is directly relevant to museum practice. Children's museums provide designed and facilitated experiences that support children's learning and development through play and open-ended exploration. As community resources, they are also dedicated to providing inclusive and welcoming environments for families of all backgrounds and cultures. Studies that elucidate the connections between explanation and exploration can help exhibit designers decide what kinds of prompts to provide for caregivers (e.g., through labels or exhibit text, or through design of the physical space to encourage social interactions and adult involvement), and they could help facilitators and educators understand how they might approach and model interactions with children (for example, which moments are most critical, and what behaviors to be aware of in the context of real-world family interactions).

In previous research, we have examined explaining and exploring in the context of parent–child interaction in children's museums using a minimal intervention design (Willard et al., 2019). The results were promising in showing that prompts for parents to encourage exploring and explaining led to distinct but fruitful activity for young children. Some of our other recent work expands these ideas to consider how children are engaged by and learn from social interaction, based on the nature of that interaction. For example, Medina and Sobel (in press) presented children and parents on the floor of a children's museum with a novel causal structure to learn, and asked parents to teach the structure to their children through free play. They found that parents who were the most directive in their instruction had children who learned particular rules the best (the rules that were more obvious from the data), but that those children were the least engaged by the act of learning (e.g., they played with the causal toy for the least amount of time). In contrast, parents who were more collaborative had children who played the longest with the toy—and were potentially most engaged by the act of learning to learn about the toy, even if they did not learn a particular rule as well as the more directive dyads. The Medina and Sobel study, however, specifically instructed parents that children would be tested about the rules that governed the causal system. Our goal here is to look at parent–child interaction in a naturalistic setting, where parents are not specifically told to teach their children and there are no right or wrong answers during free play.

Study Objectives

In this monograph, we examine spontaneous patterns of exploring and explaining that occur in families' everyday interaction in children's museums, and how these patterns might differentially predict children's causal thinking. We argue that the dynamic interaction between explanation and exploration reflects children's desire to understand the world and to participate in collaborative activity with others. Social motivation may encourage children to engage in particular kinds of systematic exploration that tests either their own or others' hypotheses. It might also affect children at a more local level—by motivating them to persist in completing a particular action to facilitate that goal. Thus, we also explored children's responses when faced with difficulty in their exhibit play, and considered their persistence at these moments as another sign that they are particularly interested in learning causal information.

We present a study on parent–child interaction, describing the ways in which children's exploration interacts with parent's and children's explanations and parent–child interaction more generally construed. We recorded parents and children playing together at an open-ended gear exhibit across three museums in different parts of the country. We then invited children to engage in a set of tasks without their parents, related to their understanding of gears. Overall, the research questions that motivate our study are as follows: (a) How do open-ended exploration, explanation, and interaction style relate to one another during family play at an exhibit? (b) How does exploration, explanation, and interaction style relate to contextual factors among families, such as families' science background? and (c) How does the relation among exploration, explanation, and parent–child interaction relate to children's causal thinking when tested on their own in more structured tasks?

An important facet of our investigation is that we looked at parent–child interaction across three children's museums in different geographic regions of the United States. Working in distinct sites has important advantages, but also raises serious concerns. In Chapter II, we describe the settings, participants, and specific procedures of the study, as well as several of the demographic findings across the three sites. Working in different geographic locations allowed us to have greater diversity than working in any individual site. However, working across three sites also meant that we conducted our research in three different children's museums, each with different missions and messaging. Moreover, as we describe in Chapter II, the three exhibits all differed to some degree. Some of those differences potentially affected the ways in which children and adults would engage with the exhibits. It is important to consider what differences are meaningful, and what differences are artifacts of the exhibit design, a point we will discuss in Chapter II, but also throughout the monograph.

In Chapter II, we also summarize many of the demographic factors that we considered might relate to exploration, explanation or interaction style. We considered certain basic demographics, such as children's and parents' age and gender (self- or parent-identified), as well as the frequency with which they visited the museum, parents' self-identified ethnicity, and two factors that are related to social-economic status (parental education level and household income). Finally, we also examined whether parents had a background in science, through their education or career. Describing these demographics allows us to consider how such demographics might relate to the exploration children generate, the explanations children and parents generate, and the general interaction style between parents and children during their free play (our second research question listed above).

To answer the three research questions we posed, we must qualify what exploration, explanation, and interaction styles mean. In Chapter III, we present a coding scheme for children's exploration, and define two distinct patterns of exploration that occur over time, which are relevant to describing both children's learning from their play and children's persisting toward particular goals. In Chapter III, we consider whether these patterns of exploration are related to the demographic information that we present in Chapter II.

Chapter IV describes our coding system for the language both parents and children generated during their free play, and how the overall frequency of those different types of language relates to children's exploratory behaviors. We are particularly interested in the causal language that parents and children generated, but as will become apparent in Chapter IV, we also highlight other kinds of talk that children engage in during the free play, as it is potentially related to sequential behaviors that indicate their ability to troubleshoot problems. In Chapter IV, we will relate the overall amount of explanatory talk that children and parents generate (as well as the language they generate more generally) to children's overall amounts of exploration, as well as to the demographics of the samples.

Chapter V presents a third coding scheme for parent–child interaction style, which is more focused on the goals of the interaction: Who is setting goals? How are those goals being set? And, who carries out the action? As in Chapters III and IV, we go on to relate this coding to the behaviors and talk that we described in the previous chapters. The general structure of Chapters III–V is to introduce a new facet of our coding the free play of children and parents, and to relate that new information to other facets of the parent–child interaction already discussed.

An important aspect of the analysis beginning in Chapter III is that we characterized children's behavior within small (5-s) time segments. These time segments then served as an anchor for our analysis of when parents or children generated causal language (e.g., analyses relating types of exploratory behavior with the presence of language generated by children and parents). So, we can also consider whether our coded talk and behavior measures are related to one another based on the dynamics—at what point in the play interaction do parents or children generate particular kinds of utterances, and does hearing or generating a particular kind of linguistic utterance affect the likelihood that one generates systematic sequences of behavior? In Chapter VI, we make use of analytical techniques that allow for testing hypotheses about microanalytical sequential patterns. Critically we test whether the occurrence of certain kinds of language relate to certain kinds of exploration at particular times over the course of the session. Our hypothesis is that children's social partners (i.e., their parents in this study) are active collaborators in children's social learning, and children are sensitive to and rely on their parents' collaboration and scaffolding in social contexts. In this way, the dynamics—*when* parents engage in particular kinds of explanations—may relate to the way children explore their environment. Children potentially use explanation to help them form hypotheses about the world, and use exploration to help them test those hypotheses, generating new information that provokes further explanation.

Chapter VII then looks at the relation between the dynamics of exploration, explanation, and parent–child interaction style and the set of outcome measures on children's causal thinking about gears. Our hypothesis is that the more children's exploration is intertwined with parents' explanation, the more likely they will appreciate the causal thinking involved in understanding relations among gears. Put another way, the more children engage in the interaction between exploration and explanation, the more likely they are to learn information about the causal structure of the world, which would be reflected in how well they perform on measures of causal thinking related to gears. In Chapter VII, we also consider how all of these variables relate to the demographic factors of the family that we describe in Chapter II. That is, we also ask what role parents' background might have in the nature of their interaction with their children during the free play.

Finally, in Chapter VIII, we explore what we have learned, both for researchers in cognitive development and for practitioners in museum settings. We revisit the interaction between constructivist and sociocultural hypotheses, and try to ground these results in that integrated theory. We also discuss the practical matters of partnering across geographic regions and with museums, as well as the limitations and future directions of this research.

II. Settings and Method

This collaborative project encompasses three research partnerships between university researchers and children's museums. As described in Chapter I, the research questions at the heart of this study are closely related not only to fundamental issues in cognitive development, but also to the missions and values of children's museums as a field, and the individual institutions involved in this study. As informal learning institutions designed for families with young children, children's museums are deeply concerned with providing opportunities for play and meaningful interactions between children and their caregivers. Nevertheless, each museum has unique goals and priorities that shape their approaches to the design and facilitation of informal learning experiences for families in their local communities. To explain the contexts of the research, this chapter discusses the goals and practices of the three children's museum partner sites, the demographics of our samples from each site, as well as parents' attitudes toward science, and the nature of the surrounding local communities. Following our description of the museum settings, we describe the gear exhibit in each museum that was the focus of the research, and then we describe the participants, materials, and procedure of our study.

Museum Settings

Providence Children's Museum (RI)—The mission statement of Providence Children's Museum is "to inspire and celebrate learning through active play and exploration." Providence Children's Museum is located in Providence, RI, and serves the surrounding southern New England community, with a focus on children ages 1–11 and their caregivers. Providence Children's Museum is a nationally recognized advocate for free play, and the staff believe that play is child-centered, self-directed, intrinsically motivated, and involves active exploration. As such, the museum's exhibits and programs place play at the center, designing experiences to promote play and exploration around different topics. Providence Children's Museum's exhibits include *Water Ways*, a water play environment in which children can interact with liquid water, ice, and mist; *Think Space*, an exhibit designed to promote the ubiquity and challenges of spatial thinking through interactive puzzles; and *Coming to Rhode Island*, a historically based pretend play space, centered on describing people who immigrated to Rhode Island from around their world, and promoting culture and diversity through stories.

Providence Children's Museum is also strongly embedded in the Rhode Island community. The museum opened to the public in 1977 within a 5,000 square foot Victorian house in Pawtucket, RI, and moved to a converted jewelry factory in Providence, RI, in 1997. It now has 8,000 square feet of interactive exhibits, an outdoor play garden, and sees over 170,000 visitors annually. Thirty-five percent of the visitors to Providence Children's Museum visit for free or for a significantly reduced admission through a variety of community-based outreach programs. The museum has also led several unique community outreach programs over the last 20 years. The first is *Families Together*, which is a collaborative program with the RI Department of Children, Youth, and Family Services that provides court-separated families with play-based, therapeutic visitation. The second is *MuseumCorps*, an AmeriCorps program that strives to deepen the connections between the museum and its surrounding communities through both STEM-focused afterschool programming in community centers, and maker experiences in Head Start classrooms. A third, new, community-linked project, the *Creativity Initiative*, is in its initial stages. This project is in collaboration with Rhode Island's creative community, aimed at building visitors' creative confidence and creative thinking through exhibitions, programs, and professional development.

Children's Discovery Museum of San Jose (CA)—The mission statement of Children's Discovery Museum of San Jose is: "to inspire creativity, curiosity, and lifelong learning so that today's children become tomorrow's visionaries." Children's Discovery Museum of San Jose encompasses 28,000 square feet of indoor exhibit space, with over 150 interactive STEAM-focused exhibits (Science, Technology, Engineering, Arts, and Math). Typically, over 400,000 visitors visit Children's Discovery Museum each year, and a recent renovation extended the outdoor exhibit space to 27,500 square feet.

Children's Discovery Museum opened in 1990. It is located in downtown San Jose in the heart of Silicon Valley, and its audience is reflective of the diverse communities comprising the San Jose/Silicon Valley region. Although many of its donors, board members, and visitors are associated with the technology sector, visitors to the museum include a cross-section of families from different educational and occupational backgrounds. Average income of visitors to Children's Discovery Museum tends to be higher than the national average, which reflects the cost of living in the San Francisco Bay Area. The museum engages in extensive outreach, partnering with local community organizations to invite and welcome families from neighboring communities who have lower income and educational levels than those of the average walk-in visitors, and to offer free admission to the museum. Children's Discovery Museum also offers events honoring a variety of community celebrations such as Lunar New Year, Diwali, and Dia de los Muertos.

Children's Discovery Museum of San Jose is the winner of the National Medal for Museum and Library Service and has received funding from the National Science Foundation (NSF) and Institute of Museum and Library Sciences (IMLS) to build exhibitions and develop programs such as *Secrets of Circles*, an exhibition designed to encourage exploration of the mathematics, science, and engineering of circles, and *Mammoth Discovery*, a set of hands-on exhibits inviting visitors to discover, find out more, and tell stories about Lupe, the local mammoth fossil found near the museum.

Thinkery (Austin, TX)—Thinkery's mission is "to create innovative learning experiences that equip and inspire the next generation of creative problem solvers." Thinkery was founded as the Austin Children's Museum in 1983 by a group of parents and educators in Austin, TX with the goal of creating a space to promote innovative new educational and cultural opportunities to local children. The Austin Children's Museum moved to downtown Austin and served the community as a traditional imaginative play museum. In 2013, the organization relocated and rebranded as Thinkery, signaling a shift to an educational focus on STEAM, inquiry-rich, play-based learning experiences and now welcomes 450,000 visitors a year. Thinkery is now located in East Austin, and has 40,000 square feet of indoor and outdoor exhibits and activities.

Thinkery emphasizes learning through active exploration and discovery, encouraging physical, emotional, and cognitive development for young learners (targeting children between the ages of 0–11) through a variety of STEAM exhibits and programs. Gallery exhibits like *Earth, Wind, Inspire*, which includes more than a dozen interactive exhibits to explore geological phenomena through hands-on exploration, and *Innovators' Workshop*, which provides a space for creative problem solving through construction and invention, allow children to engage in discovery-oriented learning. A number of initiatives are in place to increase the diversity of the museum visitors, including free admission days, subsidized school fieldtrips, and community outreach.

Summary of Museum Settings—As these descriptions indicate, the missions of the three museums strongly overlap in their focus on play, active learning, and community engagement. There are variations in the relative emphasis given to certain pedagogical practices, topics, and community initiatives, but the three museums share a commitment to providing children and families with compelling environments and supportive staff to promote informal learning. These three children's museums, and others across the United States, seek evidence-based ways to design exhibits and experiences that are inclusive and engaging for the broadest number of children and families in their communities. The theoretical assumptions of children's museums, especially those who belong to the Association of Children's Museums (www.childrensmuseums.org), tend to align with those of cognitive developmental researchers and early childhood education specialists (see www.naeyc.org)—combining constructivist views of young children as active learners with sociocultural views of the value of collaborative learning.

Exhibit Details

Each museum housed a gear exhibit, which was the exhibit under consideration in this research. The three gear exhibits were similar, but each had a distinctive design and served a distinct purpose in the context of the other exhibits in each museum. Figure 1 shows photographs of the three exhibits.

Providence Children's Museum—The Providence Children's Museum's gear exhibit was located in one section of a larger pretend play exhibition (*Coming to Rhode Island*). This exhibition is about various cultural groups who had immigrated to Rhode Island in different historical periods. The gear exhibit was part of a thematic environment focused on a community of French-Canadian immigrants who worked at textile mills in the 1800s. Other activities in this area included sorting bobbins of thread, cooking, and doing laundry with pretend play props. There was no signage directly adjacent to the gears, but other signage in the exhibit related to the various jobs at the mill, including running the machines and sorting bobbins. This gear exhibit is no longer present on the museum floor, following a renovation of Providence Children's Museum in 2017.

The gear exhibit itself included a large wooden pegboard (57″× 25″) mounted vertically against a wall, and extending from the near the floor to about 43″ in height (see top photograph in Figure 1). Given its proximity to the floor, the gear exhibit provided access for children of all ages, with parents often sitting on the floor next to their child in order to interact with them at the exhibit. The pegboard had evenly spaced holes across its surface, and wooden gears in a bin below the pegboard varied in size and contained pegs that could be inserted into the holes on the board. One gear was fixed in the center of the pegboard and could not be moved, while the other gears could be rearranged by museum visitors.

Children's Discovery Museum of San Jose—The gear exhibit at Children's Discovery Museum of San Jose exists within an exhibition called *Secrets of Circles*, focused on helping visitors to explore the math, science, and engineering of circles, and to appreciate the many uses of circles in nature and by people. The gear exhibit is a 58″× 34″ table with a magnetic surface (see middle photograph in Figure 1). Plastic hubs attached to the table magnetically can be moved around the table, and plastic gears of different sizes can be placed on top of a hub, so that children and their caregivers can explore how gears connect and work together. One larger gear, near the front of the table, is fixed and has a handle for turning the gears once they are connected. At the back part of the table, behind Plexiglas, three items (a doll, a clock, and a drill) are positioned on gears that are fixed to the table but can be connected to by other gears. A variety of different sized gears are available in an open compartment on the right side of the table for additional exploration. Signage at this exhibit says, "Try changing gears to make the dancer, clock, and drill spin faster or slower" (with translations in Spanish and Vietnamese).

Thinkery—The Thinkery gear exhibit sits within *Innovators Workshop*, an open gallery space with a mixture of art and science exhibits focused on building and creating with simple machines and hands-on materials. The gear exhibit consists of a steel powder-coated square table (38″× 30″) with a wood trim around the perimeter, a magnetic tabletop and a wooden shelf below where gears are stored when not in use (see bottom photograph in Figure 1). The magnetic gears in this exhibit were the same type as in the exhibit at Children's Discovery Museum of San Jose. Thinkery's exhibit does not, however, have any fixed gears or gears with handles, nor does it offer options to connect to objects mounted on gears as in the Children's Discovery Museum exhibit. The entire tabletop is available for manipulating gears and creating gear trains. There is no signage pertaining to this exhibit at Thinkery.

Summary of Exhibits—There are some interesting differences among the three exhibits. At Children's Discovery Museum, the exhibit affords a set of goals, such as make the doll on the gear behind the Plexiglas spin. At the other two museums, the exhibits are less goal-directed and afford more of an opportunity for free play. To preview one of our analyses in Chapter VI, we consider whether the dynamics of children's exploration and interaction with their parent differs when their actions are directed toward one of these goals as opposed to not. Children's Discovery Museum and the CA sample is the only site where we can make this comparison.

At Children's Discovery Museum and Thinkery, the exhibit is set on a horizontal table, where parents and children can sit to manipulate the gears. At Providence Children's Museum, the gear exhibit is a vertical pegboard, much closer to the floor. This gives greater access to children (particularly very young children), but might affect parent–child interaction given that some parents might not want to (or are unable to) sit on the floor. The exhibit in Providence also requires inserting gears into a pegboard, so connecting gears to one another requires two steps—inserting the gear and aligning the teeth of the gear to another that is already on the board. This increase in manual difficulty might affect the ways in which children interact with the exhibit. In Chapter III, we speak to how we coded situations in which children had difficulty with manipulating the exhibit.

Including the three exhibits in three different museums gave us the opportunity to attempt to replicate our findings in different real-world settings, each with its own idiosyncratic features. A strength of our study is that we collected data from three geographically distant museums, each with a different overall mission and a slightly different gear exhibit. Findings robust enough to hold across all three sites allow us to make conclusions with greater external validity.

Study Participants

Families with children between the ages of 36 and 84 months were recruited at each of the three sites. At Providence Children's Museum (RI), 112 children were recruited (M_{age}= 60 months, SD = 13; 59 boys and 53 girls [47% girls]). At Children's Discovery Museum of San Jose (CA), 109 children were recruited (M_{age}= 60 months, SD = 14; 51 boys and 58 girls [53% girls]); exact age for one child was not reported. At Thinkery (TX), 104 children were recruited (M_{age}= 59 months, SD = 13; 52 boys and 52 girls [50% girls]). Across sites, 325 children participated: 163 girls, 162 boys (50% girls). The data presented here were collected between Summer, 2015 and Fall, 2017. Children were invited to participate in the study with one parent or legal guardian. When other family members were present, they sometimes remained with the dyad for part of the procedure. Because the participating adult was always a parent or legal guardian, we refer to them as parents rather than using a more open-ended term (such as "caregiver"). Families with two children and two parents were sometimes included as separate participating dyads. There were six such families in our sample, two from RI and four from CA.

Parents filled out and signed the consent form, which asked for children's birthdate and parent-reported child gender. In addition, each parent filled out a Demographics Questionnaire after they finished playing with their child at the exhibit, which requested parent participants' own gender, family ethnicity, family income, and parent schooling background. The gender distribution of parents varied substantially between sites. At Providence Children's Museum, 91 parent participants were women and 20 were men (81% women). At Children's Discovery Museum of San Jose, 58 parent participants were women and 50 were men (53% women). At Thinkery, 67 parent participants were women and 36 were men (64% women). Across sites, 325 parents participated: 216 women, 106 men (66% women).

Parents were asked to identify which of the following brackets described their annual family income: <30 K, 31–50 K, 51–70 K, 71–90 K, 91–120 K, >120 K, or else to choose not to report. Parents were asked to report their level of formal schooling based on the following categories: some high school, high school graduate, some university, associate's degree, bachelor's degree, master's degree, doctorate or professional degree, or else choose not to report. Parents were also asked to report their major or focus of study in college (if applicable). We categorized these data as to whether parents had no college degree or a bachelor's degree in a non-STEM field (as indicated by the NSF guidelines for STEM), a bachelor's degree in a STEM field, or an advanced degree in a STEM field. We did include Medicine as a STEM field in this categorization (NSF does not always include Medicine in its listings). Parents were also asked how often they and their family went to the museum. The distributions of these responses are shown in Table 1.

Parents were asked to identify how they would describe their ethnicity. We categorized the open-ended responses about ethnic identity considering the NIH guidelines. Across the three sites, 137 participants reported their ethnicity as White or Caucasian (42%), 23 as Hispanic or Latinx (7%), 29 as Asian or Asian-American (9%), 5 as African-American (2%), 48 as mixed race or ethnicity (15%), and 83 did not report ethnicity (26%). The distributions of the samples across the three sites are shown in Figure 2. As can be seen from Figure 2, Children's Discovery Museum of San Jose had the largest proportion of participants who self-identified as Asian or Asian-American and Thinkery had the largest proportion of individuals who self-identified as Hispanic or Latinx. Most parents spoke English to their children. Other languages used at Providence Children's Museum were Spanish, Mandarin, Hebrew, and Portuguese; at Children's Discovery Museum of San Jose, they included Spanish, Mandarin, Cantonese, Russian, Hindi, Gujarati, Telugu, Tamil, Marathi, and French; and at the Thinkery in Austin, additional languages were ASL, Tunisian Arabic, French, Bengali, Portuguese, Mandarin, Spanish, and Dutch.

Materials and Procedure

Each family was approached by a researcher saying that, "We are interested in how children learn with their parents in the museum." The researcher invited the parent to participate in the study, explaining that they would interact with their child at the gear exhibit, and then they would come to a research room where they would fill out a series of surveys while their child played with some toys together with the researcher. If a parent agreed to participate, they were given a consent form to read and sign (including reporting child gender and birthdate), and children were asked for their verbal assent. For parents who spoke a language other than English with their child, we encouraged them to talk with the child in their home language. Spanish-speaking researchers were often present at California and Texas and could speak to parents in Spanish during recruitment. At Rhode Island some, but not all, of the testers could speak Spanish, but there was signage in both languages informing families about the research. Participating parents and children needed to speak

English to participate. The consent information and parent surveys were both in English and the researchers interacted with children in the follow-up tasks using English.

Exhibit Free Play—Parents and children were videotaped interacting with the gear exhibit for as long as they liked. In order to be included in the study, families had to be present at the exhibit for at least 90 s and had to be meaningfully interacting at the exhibit together for at least 30 s. When families signaled that they were ready to move on to the next phase, the researcher invited them into the research room, where parents were given a clipboard with surveys to fill out, and children were introduced to the follow-up tasks.

Surveys—Parents filled out three surveys. The *Attitudes toward Science* survey (Szechter & Carey, 2009) contains 15 statements on which participants responded on a 7-point scale from 1 (*mostly disagree*) to 7 (*mostly agree*). The Attitudes toward Science measure contained statements about one’s personal interest in science (e.g., “I would enjoy being a scientist”), one’s views of science and scientists (e.g., “Scientists are among the smartest people”), and one’s beliefs about the utility of science (e.g., “Thinking like a scientist is only useful when taking a test in a science class”). Parents’ overall attitudes toward science scores were calculated based on their mean agreement across the 15 items (reversing the scale on items that were worded in reverse).

The *Demographics* survey asked a series of questions about family background, including parent’s gender, age, highest grade completed in school, college major (if applicable), how frequently the family visits the museum, household income, and family ethnicity.

Follow-Up Tasks—Following Legare and Lombrozo (2014), children engaged in four followup tasks with a gear toy. The researcher showed children the gear machine construction shown in Figure 3 and demonstrated how it works. In the *Color Memory* task (Figure 4), the researcher removed one gear and then asked children which of five gears would make the machine look like it did before. All five options were the same size as the missing gear, so the correct answer involved memory for the color of the missing gear. In the *Mechanism* task (Figure 5), in contrast, the researcher removed a different gear and then showed the child five options, only one of which was the appropriate size and shape to fit in the open space and make the gear toy functional again. Children were asked which piece would make the machine work like it did before. In the *Reconstruction* task (Figure 6), the researcher took apart the entire toy and invited the child to put it back together, saying “Can you put the machine back together the way it was before and make it work?” Finally, in the *Generalization* task (Figure 7), the researcher offered some new pieces and invited children to a build a new machine, saying “Can you build a new machine with these pieces? You can make it any way you want.” For the reconstruction and generalization tasks children were given 5 min each.

Other Data Collection—Children were also given a short interview in which they asked about their understanding of science. The researcher asked, “What do you think ‘science’ means?” If children hesitated, they were told: “It’s ok if you’re not sure. You can take a guess” and then the test question was repeated. After children gave an answer, the researcher prompted once more, “Is there anything else you want to tell me about what science means?" To end on a positive (and less challenging) note, the researcher then asked children about their favorite part of the museum, then thanked both parents and children for their participation, and gave children a sticker before they returned to the museum floor. Our goal for including the question about science was to consider a brief assessment of children's knowledge about science. We coded (a) whether children generated a general definition of science or a definition that included a specific activity, (b) whether children used specific, predefined science-oriented words in their definition (like "Experiment" or "Hypothesis"); and (c) whether children articulated a definition that involved learning or knowledge change. To highlight the main finding, all of these codes correlated with children's age, but were unrelated to the other variables considered in our subsequent analyses once age was factored out of regression models. As a result, we do not consider this procedure further.

Parents also filled out an *Attitudes toward Play* survey, which was modified from Gaskins (2013). This study was an open-ended questionnaire about parents' goals for their visit and their beliefs about play and its relation to learning. Preliminary analysis, however, revealed that parents' responses on this survey were quite consistent across and within sites, and so there was little variance and relatively ceiling-level performance on this measure. Because this survey did not demonstrate variability, the answers will not be considered here.

Video Transcription and Coding—Researchers transcribed each video clip using Datavyu and Microsoft Excel software, and at least two additional research assistants checked and rechecked the original transcription. Bilingual research assistants translated videos where parents spoke a language other than English with their children. Where possible, bilingual coders coded the transcripts, and in cases where trained bilingual coders were not available for those languages, researchers coded transcripts that were translated into English. When we describe coding rubrics in Chapters III–V, we will detail the coding procedures and reliability data.

A Note About Statistical Analysis Throughout the Monograph

Throughout the monograph, we use nonparametric statistical analyses to examine our data. Nonparametric analyses are often used to analyze nominal or ordinal data. These analyses do not make specific assumptions about the underlying distribution of the population (e.g., that it is normally distributed). We decided at the outset of our analyses to take this approach everywhere it was possible for a variety of reasons. In many cases, we take this approach because we are analyzing ordinal or nominal variables, and parametric analyses would simply be inappropriate. In other cases, we are analyzing distributions that are not normally distributed. Nonparametric tests are also less affected by outliers in the data because they are measuring the central tendencies of the sample.

In the few cases where parametric tests would be appropriate, nonparametric tests are equally valid, and often thought to be more robust. Indeed, many argue that nonparametric tests are more reliable than parametric ones given that they apply in more situations and do not make assumptions about the underlying population (e.g., Siegel, 1956). Hence, they potentially generate more externally valid results. The main disadvantage of these tests is that they often require larger samples to ensure the same statistical power as parametric analyses. However, given our combined data set, we believed that we had a large enough sample size to ensure appropriate statistical power.

Relations Among Attitudes Toward Science and Demographic Questions

Overall, 312 parents filled out the Attitudes toward Science questionnaire. Here, and throughout the monograph, we do not include cases in which parents did not provide necessary demographic information, which is reflected in the different degrees of freedom for the analyses reported throughout. The mean response to the Attitudes toward Science questions was 5.31 out of a possible score of 7 ($SD = 0.74$). There was some variation among the three sites, however, with the highest mean from the sample collected at Children's Discovery Museum of San Jose (5.45), followed by Providence Children's Museum (5.26), and Thinkery (5.18). The difference among the sites was significant, Kruskal–Wallis $\chi^2(2) = 7.29$, $p = .03$. Simple effect analyses were performed with a Dunn–Bonferroni correction. These analyses showed that parents at the Children's Discovery Museum scored significantly higher than the Thinkery sample, Mann–Whitney $z = -2.56$, $p = .03$. The Providence Children's Museum and Thinkery samples did not significantly differ from one another, $z = -0.67$, $p = 1.00$, nor did the Providence Children's Museum and Children's Discovery Museum samples, $z = -1.99$, $p = .14$.

Table 2 shows a zero-order correlation matrix of all parent demographics and attitudes toward science scores across sites. Parents' responses to the attitudes toward science questions did not correlate with their children's age (which here, and throughout the monograph, will be analyzed in months), $r_s(309) = -.02$, $p = .69$, or gender, $r_s(310) = .05$, $p = .39$. Attitudes toward science scores also did not correlate with parents' age (as measured by the ordinal categories we presented), or with the frequency with which the family visited the museum (see Table 2 for statistics). Attitudes toward Science did correlate with parents' gender, $r_s(308) = -.16$, $p = .004$, with fathers (5.46) scoring higher on average than mothers (5.23).

Parents' schooling level and income level positively correlated with both Attitudes toward Science, $r_s(299) = .25$, $p < .001$ and $r_s(279) = .25$, $p < .001$, respectively. We also observed a correlation between parents' Attitudes toward Science and whether they had a science background: We used an ordinal scale, assigning a score of 2 for families with an advanced degree in a STEM field, a score of 1 for a Bachelor's degree in a STEM field, and a score of 0 for a Bachelor's degree in a non-STEM field or not having a Bachelor's degree, $r_s(310) = .38$, $p < .001$.

To attempt to isolate unique variance, we constructed a general linear model on parents' Attitudes toward Science responses, looking at a model with these independent variables (i.e., gender of parent, science background, parents' schooling level, household income, and museum site). The overall model was significant, $\chi^2(7) = 48.88$, $p < .001$. The only variable that explained a unique amount of variance was parents' background in science, $\chi^2(2) = 21.47$, $p <.001$, with parents who did not have a bachelor's in STEM and parents with a bachelor's in STEM both reporting lower Attitudes toward Science than parents with an advanced degree in STEM, $\beta = -0.62$ $SE = 0.14$, Wald $\chi^2(1) = 21.09$, $p < .001$ and $\beta =$

−0.40 SE= 0.13, Wald $\chi^2(1) = 9.26$, $p = .002$. None of the other factors predicted unique variance in this model.

We were also able to examine Attitudes toward Science responses in light of parents' self-identified ethnicity. The three categories that were identified most frequently were White or Caucasian, Latinx or Hispanic, and Asian or Asian-American. We chose to focus on these three categories in our analyses for reasons of sample size. There was an overall difference among the three categories in terms of scores on the Attitudes toward Science questionnaire, Kruskal–Wallis $\chi^2(2) = 12.36$, $p = .002$. As above, we built a general linear model to attempt to isolate the role of ethnicity category, museum site, and parents' science background. Science background again explained a significant amount of variance, Wald $\chi^2(1) = 27.92$, $p < .001$, but ethnicity category and museum site were not significant in this model. Overall, these data suggest that while there are differences in the attitudes reported by ethnicity in our sample, self-reported ethnicity itself did not predict differences in parents' responses to the Attitudes toward Science questionnaire. Moreover, site differences alone do not account for differences in the Attitudes toward Science score. Rather, other demographic factors (particularly science background) that might have more variance across the sites may account for the differences in scores on the Attitudes toward Science measure across the three sites.

Even with a large sample, and care taken to recruit participating families from museums—particularly museums that offer high rates of free admission or sliding scales—our ability to answer questions about how diversity of our sample relates to other variables is limited. Even in the museum with the highest levels of reported diversity, some parents preferred not to respond to the ethnicity question, and there are few ethnic groups with large enough samples to be considered as a group. Further, given the analysis reported here on Attitudes toward Science, which suggests that there is not a unique effect of ethnicity but rather that observed differences are better explained by other demographics, our plan is to focus on those other demographics throughout the monograph as a way of potentially explaining individual differences in parents' and children's behaviors. We return to the discussion of ethnicity as it relates to parent–child interaction style, however, and again when we discuss our findings in Chapter VIII.

General Analysis Plan for the Monograph

Given the research questions that we described in Chapter I, our goal is to unpack different aspects of parents' and children's behavior while playing at the exhibits. We start by describing the ways children explored the gear exhibit over time. We used a microcoding technique to examine behaviors over short intervals of time, but also to capture how exploration changed over the course of the family's interaction with the exhibit. This technique, of course, also allowed us to provide a summary of the types of behaviors during the exhibit visit. In Chapter III, we present this coding scheme and define particular sequences of behavior that we thought might be important for children's causal thinking and problem solving. We document the frequency of those behaviors and whether they relate to the demographic data that we have presented in this chapter.

We next consider the language that both parents and children generate during their play. We present our coding scheme for language in Chapter IV. We are particularly interested in the kinds of causal explanatory language that both parents and children generate, but we focused on coding all utterances generated by both parents and children, and also specifically when they generated those utterances—how it coincided with the children's exploratory behaviors. In Chapter IV, we consider the proportions of different types of language, how those proportions related to the demographic information we presented in this chapter, as well as how the language children heard and generated related to the overall proportions of children's exploratory behaviors.

Our goal in coding the timing of children's exploratory behaviors and the language that parents and children generated was to examine their dynamic—the ways in which they might relate to one another in time. Before we did that in our analyses, however, we wanted to consider a third facet of how parents and children played at the exhibit together—a more holistic description of the parent–child interaction style, based on who was setting the goals for the play. We borrowed from a coding system that we had used previously (Fung & Callanan, 2013). This coding system defined whether the play was led more by the parent, the child, or was more collaborative in terms of goal setting and how those goals were accomplished. We describe this system in detail in Chapter V, and present how that analysis related to the demographic information presented in the current chapter, and whether it related to differences in exploratory behavior or either parents' or children's language as presented in Chapters III and IV, respectively.

In Chapters III–V, our analysis plan was largely correlational. We calculated zero-order correlations to determine whether relations exist among variables, and then used techniques to isolate unique effects of particular variables, based on the correlation matrix. In keeping with our discussion of statistics above, in addition to nonparametric analyses to compare groups, we also use ordinal or binomial logistic regression techniques to ensure the robustness of our analyses.

In Chapter VI, we examine how children's exploration and the parents' and children's own language that related to that exploration in frequency (as documented in Chapter IV) related to that exploration in time. We used general linear mixed modeling to consider the timing of particular exploratory behaviors, contrasting models of when particular kinds of language were generated by the parent or the child. This analysis allows us to examine whether children's behaviors change over the course of the observed play, and whether parents' or children's language relates to their generating particular kinds of exploratory behaviors given when that language occurs during their exploration. Moreover, we also explored how parent–child interaction styles might have related to the dynamic between exploration and language.

These analyses all focus on the behaviors while families played at the exhibit. In Chapter VII, we relate aspects of this play to the follow-up measures that we described here in this current chapter. In Chapter VII, we present our coding systems for the follow-up measures on gears (particularly in the ways in which they differ from those used by Legare & Lombrozo, 2014). We use a principal component analysis to determine how coding for the follow-up measures are related to each other. That analysis isolates variables we believe to be related to children's causal thinking, and we examine how the facets of our coding relate to that causal thinking. To do this, we built a set of structural equation models, representing the ways in which we suggest various aspects of behavior during the free play at the exhibit relate to how children think about the causal relations among gears. Finally, in Chapter VIII, we bring the discussion back to the relation between constructivist and sociocultural approaches and discuss lessons we learned from our investigation.

Discussion

Children's museums differ in their environs and in their missions. This is apparent in the relative differences among the three gear exhibits, which form the basis of potential differences among the results we will describe. The three museums participating in this research also differ in their stated focus on STEM experiences and in the ways in which they communicate that information to the general public. As a simple example, while the three first authors were in the process of applying for funding for this project, Austin Children's Museum rebranded as Thinkery, which included a large-scale renovation and new mission with more of an emphasis on STEAM engagement. After we began our investigation, our collaborators at Providence Children's Museum highlighted the difference between a children's museum and a science center. They emphasized they were the former and not the latter; their focus was on the developing child in a more holistic manner and not simply STEAM engagement. In contrast, our collaborators at Children's Discovery Museum emphasized that they were a hybrid—with elements of both a children's museum and a science center, and emphasized the validity of both perspectives. As the only museum partner who had received multiple National Science Foundation grants prior to this collaborative project, they also took the lead on shaping our early research-practice partnership goals.

An advantage of our multisite approach is that is allowed us to capture certain variability in our sample that sampling from any one of the sites would not, as well as the possibility of exploring variability which might suggest interesting links to distinct qualities of the museums and audience. There were demographic variation and similarities among the participants at the three museums. For example, there was variation across sites in the ethnic backgrounds of participating families, their family income, parental gender, and parental background in science, but similarities across sites in parental schooling. We found correlations between various demographic variables and Attitudes toward Science scores across sites. For example, parents' schooling level and income correlated with Attitudes toward Science, as did parental science background. Site did not explain significant variance in this analysis.

We hope to have conveyed a sense of the families' experiences as they visited each of our partner museums. As shorthand to refer to the individual museum contexts when describing methods, analyses, and findings, in Chapters III through VII we will refer to each museum by their state abbreviations (viz., RI, CA, and TX). We will return to using the full names of each museum in our closing general discussion (Chapter VIII).

III. Children's Exploration

The objective of this chapter is to document exploration by describing how children played at the gear exhibits with their parents. First, we present our coding scheme for capturing children's exploratory behaviors. Next, we examine whether there were differences in these behaviors and sequences of behaviors depending on the demographic factors of participants. The coding scheme for children's exploratory behaviors forms the basis of analyses we will conduct in later chapters.

Our approach for examining children's exploration was to divide the free play session into 5-s time segments and code and analyze the nature of children's behavior during each segment. Segmentation by time allowed us to analyze the frequency of different kinds of behavior, their complexity and relevance to exploring causal function, and the joint probabilities among different kinds of behaviors.

We defined two categories of behavior a priori that we believe were important for children's causal thinking based on their actions at the exhibit. The first is what we call *systematic exploration*—the act of generating causal relations from the gear machines that children construct (i.e., when children tested gear machines that they had just constructed). The second is what we call *resolute behavior*, which we define as the act of successfully resolving attempts to engage in certain actions that are challenging because of the nature of the exhibit. We describe the importance of these behaviors later in the chapter, when we present descriptive analyses of these behaviors. These measures of systematic exploration and resolute behavior become important for analyses in Chapters VI and VII, which test models linking exploration with explaining, parent–child interaction style, and measures of individual differences across families.

Coding

Coding Scheme for Exploration—We coded each 5 s segment of the free play into one of a set of mutually exclusive categories that focused on children's behaviors (described in Table 3). We use the term *gear* to refer to children manipulating an individual gear and the term *gear machine* to refer to children manipulating a set of connected gears. If different behavioral categories occurred during the 5 s, the segment was coded according to which behavior dominated the segment.

Coding and Reliability—At each site, interrater reliability was calculated by having two coders, naïve to the hypotheses of the study, code 20% of the videos at their site. Coder agreement was 87% (κ = .84) in RI; 78% (κ = .70) in CA, and 88% (κ = .82) in TX. Prior to obtaining reliability, coders at all three sites practiced coding a set of videos from all three sites and discussed disagreements via conference calls. Coders in RI also coded three additional videos from each of the CA and TX sites. Agreement on these codes was 86% (κ = .80). This process ensured agreement in coding within each site, and also among the three sites. Disagreements were resolved through discussion among the coders and one of the authors.

A note on κ values. Although Cohen (1960) suggested that κ values over .41 could be deemed acceptable reliability, we followed McHugh (2012), who suggested that κ values below .60 are not acceptable, those between .60 and .80 represent moderate agreement and values between .80 and .90 represent strong agreement. Given the difficulties of having multiple coders work across the three sites, we adopted McHugh's criterion of moderate agreement (i.e., κ values above .60) as acceptable for data analysis throughout the monograph. We report all raw agreement percentages and κ-values; all κ-values throughout the monograph are ≥.70.

Results

Mean Proportions of Types of Exploration—To examine how often children engaged in the different exploratory behaviors, we compared how often time segments were coded as each exploration type by age and child gender across the three sites. Due to experimental error, one child in the CA sample was not coded, and those data will not be part of the rest of analysis. On average, children stayed longer at the exhibit in CA (M = 479 s, SD = 261 s) than in TX (M = 354 s, SD = 219 s) or RI (M = 317 s, SD = 255 s), Kruskal–Wallis $\chi^2(2) = 32.44$, $p < .001$. Because time spent on the activity varied across sites and families, we calculated proportions of time segments coded in each category as a function of total codable time segments. Figure 8 shows the proportion of the total codable time segments that were coded in each category across the three sites. To remind the reader, many of these proportions were not normally distributed (based on one-sample Kolmogorov–Smirnov tests) and many of the analyses reported here involve ordinal or nominal variables. Because of this, we used nonparametric analyses here and throughout the monograph. For each category except Exploring Connections, these proportions differed across the three sites, all Kruskal–Wallis $\chi^2(2)$-values > 9.36, all p-values <.01. As a result, we analyzed our data both by individual sites and for the full data set.

Table 4 shows the correlations among age, children's gender, and the proportion of each category of exploration across the three sites. Two commonalities emerged from these analyses. Across all the sites, the proportion of time children spent not exploring the exhibit decreased with age and the proportion of time children spent exploring connections increased with age. As expected, when the data from the three sites were combined, these correlations were also present, $r_s(321) = -.29$, $p < .001$ and $r_s(321) = .37$, $p < .001$. Analysis of the overall data set also revealed that older children spent proportionally less time exploring individual gears, $r_s(321) = -.16$, $p = .003$, and they spent proportionally more time attempting to connect gears together and attempting to spin gear machines than younger children did, $r_s(321) = .21$ and .18, both p-values <.001. Correlations were in the same direction across all three sites, but each was only significant in two of the three sites. In contrast, the proportion of time spent exploring gear machines did not correlate significantly with age in the overall data set, $r_s(321) = -.02$, $p = .77$, and there were no consistent patterns across the three sites in the time spent engaged in spinning behavior.

Finally, we looked at the relation between each kind of exploration and children's gender. The overall data set revealed a few differences by gender. The proportion of time spent not interacting with the exhibit was higher for girls than boys in the overall sample, $r_s(322) =$

.12, $p = .04$, but this difference was not significant in any individual site (see Table 4). Boys spent a greater proportion of time exploring connections than girls did, $r_s(322) = -.16$, p = .003, and this was significant in two out of the three sites (TX and CA). Finally, boys also spent a greater proportion of their time attempting to explore connections than girls did, $r_s(322) = -.11$, p = .04, but this was only significant in one of the three sites (TX).

Probability Distributions of Exploration Sequences—Our coding scheme allowed us to examine not only the frequency of individual behaviors, but also patterns of behavior over time. To begin this analysis, we looked at the frequency of these categories cooccurring —that is, the number of times that children explored in a certain way for one 5-s interval, and explored in another way for the subsequent 5-s interval. These contingent probability values indicate the likelihood of a particular sequence of behaviors occurring together, considering the frequency with which each category appeared at any point during the free play. We defined a priori two sequences of actions that reflect exploratory behaviors of interest:

1. *Systematic Exploration*: Systematic exploration is the frequency with which children connected a gear to at least one other gear (i.e., explored a connection) and then spun (or attempted to spin) the gear to observe the effect of that connection (i.e., explored or attempted to explore a machine). This behavior reflects the extent to which children tested gear machines that they constructed. We view this behavior as a potential indication of children's causal thinking during the free play.

2. *Resolute Behavior*: Resolute behavior is the frequency with which children attempted a particular action (trying to connect or spin a machine) and did not succeed, but resolved this difficulty by successfully connecting the gears or spinning the gear machine in the next 5-s interval. Our goal for analyzing this behavior was to document the frequency with which children persisted in an action in order to accomplish a goal. Although we describe this behavior at a relatively micro level, we view this behavior as a potential indication of children's willingness to persist during free play even when their actions are not immediately successful.

We first looked at differences in these two joint behaviors across the three sites and their relation with children's age and gender. These data are shown in Table 5.

Systematic Exploration: The frequency of systematic exploration did not differ among the three sites, Kruskal–Wallis $\chi^2(2) = 2.28$, $p = .32$. Systematic exploration did significantly correlate with children's age (see Table 5). As a result, all subsequent analyses of the systematic exploration measure include age as a covariate. In addition, boys engaged in a significantly higher proportion of systematic exploration than girls did overall, although as Table 5 shows, this was only significant in CA and TX.

Next, we examined the relation between systematic behavior and other demographic factors of the participants. We found that the frequency of systematic exploration did not correlate with the parent's age, $r_s(319) = .04$, $p = .52$, or gender $r_s(315) = .04$, $p = .52$, or the frequency with which the family visited the museum, $r_s(315) = .04$, $p = .50$. The frequency of systematic exploration did correlate with parental education level, $r_s(306) = .12$, $p = .04$, but not with household income, $r_s(285) = .04$, $p = .47$, or whether parents had a college degree or advanced degree in STEM, $r_s(322) = -.03$, $p = .62$.

Resolute Behavior: The frequency of resolute behavior differed among the three sites, Kruskal–Wallis $\chi^2(2) = 6.00$, $p = .05$. Post-hoc tests with a Dunn–Bonferroni correction revealed that children from RI showed more resolute behavior than children in CA, $z = 2.44$, $p = .04$. There was no difference in the amount of resolute behavior between RI and TX, $z = 1.31$, $p = .57$ or between TX and CA, $z = -1.10$, $p = .81$. Because the gear exhibit in RI was a vertical pegboard, as opposed to a horizontal magnetic table in CA and TX, children might have had more difficulty connecting gears together. In order to connect two gears in RI, children had to align the teeth on the gears in order to be able to stick the peg into a hole on the pegboard. In contrast, at the other two sites, children often performed these actions sequentially, by first placing the gear on the table and then sliding it across the surface to interlock the teeth, which was easier to accomplish. These differences among exhibits resulted in many fewer connection attempts in CA and TX than in RI.

We found significant correlations between resolute behavior, and children's age, and gender, as shown in Table 5. Overall, with age, children engaged in more resolute behavior, and this correlation was significant in both RI and TX. As a result, all subsequent analyses of resolute behavior include age as a covariate. Considering children's gender, boys had a higher proportion of resolute behavior than girls, but only in the TX data set. Again, we will also consider gender as a covariate in further analyses.

Looking at other factors in the overall data set, there were no significant correlations between the proportion of children's resolute behavior and parents' age, $r_s(315) = .09$, $p = .13$, parents' gender, $r_s(319) = -.05$, $p = .35$, household income, $r_s(285) = .09$, $p = .14$, parents' education level, $r_s(306) = .04$, $p = .49$, parents' science background, $r_s(322) = <.01$, p= .96, or how often families visited the museum, $r_s(315) = .03$, $p = .63$. These factors will not be considered further.

Relations Between Systematic Exploration and Resolute Behavior—There was a significant correlation between the proportion of systematic exploration and the proportion of resolute behavior that children engaged in across the overall data set, $r_s(322) = .49$, $p < .001$, and this correlation was significant at all three sites, $r_s(110) = .46$, $p < .001$ in RI; $r_s(106) = .26$, $p = .006$ in CA; $r_s(102) = .75$, $p < .001$ in TX. To account for the correlations with children's age and gender, we constructed a general linear model assuming an ordinal response on the proportion of children's systematic exploration, with children's age, gender of the child, and proportion of resolute behavior as independent variables. Children's age and gender were both significant factors, β= .40 and .56, SE = .01 and .20, Wald $\chi^2(1)$ = 20.59 and 7.65, $p < .001$ and $p = .006$, respectively. The proportion of resolute behavior also predicted a unique amount of variance in systematic exploring, $\beta = 26.54$, $SE = 4.32$, Wald $\chi^2(1) = 37.67$, $p < .001$.

Discussion

The objective of this chapter was to describe the behaviors children engaged in at the gear exhibits. We divided the free play sessions into a set of 5-s intervals, and coded the nature of children's behavior with the gears in each interval. This coding system does not capture all of the richness of the play that children and parents engaged in, but it does capture key behaviors relevant to the causal systems in the exhibits: children sometimes interacted with individual gears without connecting them, they sometimes connected gears (or attempted to), and they sometimes spun individual gears or gear machines. These behaviors, and the sequences of these actions, revealed systematicity in children's exploration and resolute behavior as children persisted in trying to build and test the gear machines they constructed.

Parents and children engaged in different types of exploration with the gear exhibits, perhaps due to variation in the exhibits at the three museums. Yet consistent patterns of behavior were evident. As children got older, they engaged in more systematic exploration, and this systematicity did not clearly relate to the demographic characteristics of the sample. Similarly, older children engaged in more resolute behavior—behavior that indicated persistence in trying to test a gear machine even when children were not immediately successful. Critically, systematic exploration and resolute behaviors related to one another (and did not seem to be mediated by other factors), suggesting some coherence between children's exploration and problem solving.

Few demographic characteristics of our sample related to children's systematic exploration or resolute behavior. There were no differences across sites in systematic exploration, but there were differences in the frequency of resolute behaviors. We will discuss the absence of differences among the sites regarding systematic exploration in Chapter VIII, as this variable will be important in our subsequent analyses. Moreover, we will discuss the differences among the sites regarding resolute behavior further in Chapter VI, as this difference will motivate us focusing on the RI data set to examine the dynamics between this exploration and explanation and parent–child interaction, which we will describe in the next two chapters.

As in Chapter I, we will preview how our next analyses will unfold. In Chapters IV and V, we look more carefully at the relation between children's systematic exploration and resolute behavior, and relate these behaviors to other facets of the free play. The differences we have documented here suggest two distinct analysis strategies, which we will consider throughout the rest of this monograph. We will consider how these patterns within children's play relate to the language they hear and generate (Chapter IV), and to the parent–child interaction style observed at the exhibit (Chapter V). In both cases, we take a similar strategy to what was presented in this chapter—looking at the overall data set, and among the three sites.

Next, in Chapters VI and VII, we consider the dynamics among these factors. In the present chapter, we analyzed the proportion of behavior of certain types across the entire free play session (e.g., the proportion of children's systematic exploration and resolute behavior), but not the timing of those behaviors, or how they may interact with one another dynamically. Chapter VI attempts to examine the dynamic interactions between children's exploration, parents' and children's causal explanatory language, and parent–child interaction style, considering how they relate to one another in a sequential analysis. Chapter VII then proposes a structural equation model, which examines how family demographic measures predict action and talk in the free play session, and how action and talk in the free play session predict children's causal thinking in the follow-up measures described in Chapter II. Finally, in Chapter VIII, we discuss conclusions and implications of these analyses based on the theoretical background provided in Chapter I.

IV. Parents' and Children's Language

In the previous chapter, we described how children explored the gear exhibits. The objective of the current chapter is to document the language used by parents and their children while playing at the gear exhibits. To this end, we coded the frequency of different kinds of utterances. We were especially interested in explanatory talk, so we coded several types of causal statements and questions. To create an exhaustive coding scheme, we also coded a variety of other types of noncausal statements and questions. We then examined how parent and child utterances appeared in conjunction with children's exploration.

As in Chapter III, we first describe the coding scheme that we used to characterize parents' and children's utterances. Next, we examine relations among demographic variables and frequencies of key types of utterances in parent–child conversations. Finally, we examine how specific types of utterances relate to specific exploratory behaviors in total. Later in the monograph (Chapter VI), we examine how exploration and explanation co-occurred in time.

Coding

Coding Scheme for Explanation—All free play sessions were transcribed and then parsed into individual utterances. To identify utterances, we initially relied on the transcribers' use of punctuation to capture prosody and pauses indicating ends of sentences. Next, parsing was checked; we parsed any full sentence transcribed with a period or question mark as an utterance. Sentences transcribed with commas were parsed separately if each side of the comma conveyed a full thought (e.g., "Alright spin it, let's see if it works," was parsed as two utterances). Single word utterances were considered as separate utterances; false starts and incomplete sentences were parsed separately but not coded.

All utterances were timestamped with the onset time, so that utterances could be matched to the corresponding 5-s windows in the exploration coding (as described in Chapter III). Parents' utterances were coded if they were directed specifically at the participating child. Children's utterances were coded if they were directed specifically at the participating parent. Nonverbal behavior was indicated in the transcript (including nods, shrugs, head shakes, laughs, or gasps), but coded only when relevant to one of the verbal coding categories described below. When a parent or child made a false start in their utterance (e.g., "I wonder if—let's put it over here"), the code was based on only the second part of the sentence, ignoring the false start. Coders used the transcripts while watching the video.

The coding scheme for parents' and children's talk is described in Table 6, with definitions as well as examples provided. To simplify the coding process, we organized our coding scheme into a hierarchy. This hierarchy was given to our coders, so that they could more easily categorize certain utterances into one part of the coding system, and then determine the precise code.

The first section of the hierarchy included five types of causal language about the exhibit mechanism, with statements and questions coded for each type. These included causal connections, predictions, personal connections (somewhat like analogies), science principles, and descriptions of aspects of the exhibit relevant to the causal mechanism. The second section included talk that was more descriptive than causal, and focused either on the nonmechanistic aspects of the exhibit or on the actions of the people involved. The final section included noncausal talk focused on other topics such as guiding attention or praising.

Coding and Reliability—We remind the reader of our discussion about κ values from Chapter III, in which we stated that κ values for agreement between coders should reflect at least moderate agreement. Three naïve coders all coded the same randomly selected 20% of the RI sample. Agreement among each pair of coders was over 80%. κ values among each pair of coders ranged from .73 to .81. These three coders also coded nine videos from across the three sites to make sure that they agreed with the coding being done by the other two sites. κ values among each pair of coders ranged from .71 to .83. Disagreements in all cases were resolved through discussion among the three coders and one of the authors. These three coders then coded the rest of the RI data independently.

Two naïve coders coded a randomly selected 20% of the CA sample. Their agreement was 81%, $\kappa = .79$. Disagreements were resolved through discussion among the coders and one of the authors. Then, the two coders each coded roughly half of the remaining videos.

Two pairs of naïve coders coded a randomly selected 20% of the TX participants. Reliability for parent and child talk was calculated separately, agreement between coders was over 80% for both pairs of coders. κ values among each pair of coders ranged from .85 (parent talk) to .90 (child talk). Disagreements were resolved through discussion with one of the authors, and the two coders each coded roughly half of the remaining videos.

Results

Parents' Talk—Table 7 shows the average proportion of parents' utterances for each code at each site. As shown in this table, there were differences among sites in amounts of causal language generated by parents, with the largest proportion in CA and the smallest in TX. Other types of parent talk also differed among the three sites. As examples, RI parents generated more directive statements and fewer narrative statements than parents at the other two sites. TX parents generated more scaffolding statements and open-ended questions than those at the other two sites. RI parents also generated more praise statements than parents at the other two sites.

Our planned analyses focused on whether there were relations between demographic variables and each broad category of parental talk, and whether these differences could explain some of the site differences presented above. We looked at the relations among the three broad categories of parents' language and children's age, children's gender, parents' gender, parents' educational level, household income, and frequency of visits to the museum, as well as parents' answers on the Attitudes about Science questionnaire. There were no significant correlations between any of these variables and the proportion of talk about exhibits or actions, or the proportion of other talk. Parents' causal talk, however, did correlate with three of these demographic factors. The first was children's age, $r_S(322) = .14$, $p = .01$, with parents of older children generating a higher proportion of causal talk. When sites were examined individually, this correlation was only significant in TX, $r_S(102) = .36$, $p < .001$. Parents' causal talk also correlated with (a) parents' educational level, $r_S(307) = .15$, $p = .01$ and (b) household income, $r_S(286) = .16$, $p = .008$. Both of these correlations were significant for the full data set but not for any single site examined individually. Although these two correlations were weak, we considered them in subsequent analyses.

Finally, there was a significant positive correlation between the proportion of parents' causal talk and parents' responses to the Attitudes toward Science questionnaire, $r_S(310) = .20$, $p < .001$. As discussed in Chapter II, there were also significant correlations between responses to this questionnaire and other demographic factors, and we therefore consider the unique variance explained by this questionnaire in Chapters VI and VII.

Children's Talk—Table 8 summarizes the coding of children's utterances for the three sites. As we found with parents' utterances, the proportion of children's talk about exhibits and actions did not significantly correlate with any of the demographic variables we considered. The correlations between children's causal talk and demographic variables paralleled our findings for parents' talk. Children's age was positively correlated with the proportion of their causal talk, $r_S(322) = .15$, $p = .008$, and negatively correlated with the proportion of their other talk, $r_S(322) = -.12$, $p = .04$. These effects, however, only held in the TX data set, $r_S(102) = .27$, $p = .007$ and $r_S(102) = -.23$, $p = .02$, respectively.

Household income was also positively correlated with the proportion of children's causal talk, $r_S(286) = .13$, $p = .03$. The correlation between income and causal talk was again only found in the TX data set, $r_S(102) = .25$, $p = .02$. These findings suggest that we treat site differences, as well as children's age, household income, and parents' educational level as factors in subsequent analyses.

Finally, we considered the relation between the proportion of children's talk and their parents' responses to the Attitudes toward Science survey, but no significant correlations were found, $r_S(310) = .05$, $p = .36$ for causal talk, $r_S(310) = -.04$, $p = .50$ for talk about actions and the exhibit, and $r_S(310) = -.06$, $p = .29$, for other talk. The Attitudes toward Science scores will not be considered further in the analyses of children's talk.

Relations Between Parents' and Children's Talk—Overall, there was a significant relation between the proportion of parents' talk that was categorized as causal and the proportion of children's talk that was categorized as causal, $r_S(323) = .37$, $p < .001$. This correlation was also significant at all three sites individually: RI, $r_S(110) = .31$, $p = .001$; TX, $r_S(102) = .34$, $p < .001$; CA, $r_S(107) = .26$, $p = .006$.

There was a significant relation between the proportion of talk about the exhibit and actions generated by parents and by children, $r_s(323) = .22$, $p < .001$. This relation held in two of the three individual sites: TX, $r_s(102) = .30$, $p = .002$ and CA, $r_s(107) = .25$, $p = .009$, but not in RI, $r_s(110) = .13$, $p = .19$. There was also a significant relation between the proportion of other talk generated by the parents and by children in the overall data set, $r_s(323) = .22$, $p < .001$. Again, this correlation was significant in two of the three sites: RI, $r_s(110) = .28$, $p = .003$ and TX, $r_s(102) = .30$, $p = .002$, but not CA, $r_s(107) = .07$, $p = .50$.

Given our focus on learning from explanation, we planned to examine the causal language generated by both parents and children in subsequent analyses. To investigate the relation between the proportion of parents' and children's causal language further, we built a general linear model on the proportion of children's causal language, isolating the unique variance of children's age, parent educational level, household income, parent attitudes toward science, and the proportion of parents' causal language, talk about exhibits and actions, and other talk. The overall model was significant, $\chi^2(7) = 41.44$, $p < .001$. The only factor that significantly predicted a unique amount of variance was the proportion of causal talk generated by the parent, $\beta = 0.47$, $SE = 0.15$, Wald $\chi^2(1) = 10.05$, $p = .002$. Household income was marginally significant in this model, $\beta = 0.01$, SE = 0.01, Wald $\chi^2(1) = 3.78$, $p = .052$.

We ran similar analyses on the proportion of children's talk about exhibits and actions. Again, the overall model was significant, $\chi^2(7) = 14.56$, $p = .04$. In this model, the only factor that predicted a unique amount of variance was the proportion of parents' talk about exhibits and actions, $\beta = 0.50$, $SE = 0.23$, Wald $\chi^2(1) = 4.52$, $p = .03$. We also ran this analysis on the proportion of other kinds of talk generated by children. This revealed a significant overall model, $\chi^2(7) = 31.28$, $p < .001$, and unique effects of the proportion of parents' talk about exhibits and actions, $\beta = -0.56$, $SE = 0.23$, Wald $\chi^2(1) = 5.92$, $p = .02$, and the proportion of parent's causal talk, $\beta = -0.85$, $SE = 0.24$, Wald $\chi^2(1) = 12.29$, $p < .001$. In this analysis, however, the relations were inverted: the higher the proportion of parents' talk about exhibits and actions and the higher the proportion of causal talk generated by parents, the lower the proportion of children's other talk.

In general, these data show that the proportion of causal language generated by parents during the free play session related to the amount of causal language produced by children. This relation was not mediated by any family demographic factors, not even by children's age or parents' attitudes about science. The relation between parents' and children's causal language is unique—causal talk on the part of the parent had no relation to any other kind of talk on the part of the child.

Relations Between Parents' and Children's Talk and Children's Exploration— To what extent does children's exploration, as documented in Chapter III, relate to children's talk or parents' talk during free play? In this section, we consider how the language generated by parents and by children related to the two types of exploratory behaviors defined in Chapter III—children's systematic exploration and their resolute behavior. Table 9 shows the zero-order correlations among parents' and children's talk and these two behaviors. We highlight only the significant correlations below.

Systematic Exploration and Parent–Child Talk: Systematic exploration on the part of children—connecting gears to and then spinning them—was significantly correlated with the proportion of parents' talk that was coded as causal during free play (see Table 9). To examine this finding in more detail, we built a general linear model (GLM) with the proportion of systematic exploration as the dependent variable. Independent variables included the proportion of parents' talk that was causal, as well as variables that were significantly correlated with children's systematic exploration or parents' causal talk in previous analyses—these included children's age and gender, site, parents' educational level, and household income. The overall model was significant, likelihood ratio $\chi^2(7) = 48.33$, $p < .001$. Children's age and gender explained a significant amount of unique variance, $\chi^2(1) = 27.25$ and 8.39, $p < .001$ and $p = .004$, respectively, as did parents' educational level, $\chi^2(1) = 6.08$, $p = .01$. The proportion of parents' causal talk was marginally significant, $\chi^2(1) = 2.86$, $p = .09$. We investigate this relation further in Chapter VI, examining the timing of parents' causal language and its relation to children's actions during the play session.

Resolute Behavior and Parent–Child Talk: Resolute behavior—the proportion of times children were successful in connecting or spinning gears after an initial unsuccessful attempt —was significant correlated with the proportion of children's talk about exhibits and actions (see Table 9). We adopted the same analysis strategy as above, constructing a general linear model with children's age, gender, site, and the proportion of children's talk about exhibits and actions as independent variables. The overall model was significant, likelihood ratio $\chi^2(5) = 35.34$, p < .001. Children's age, $\chi^2(1) = 9.69$, $p = .002$, gender, $\chi^2(1) = 4.93$, $p = .03$, site, $\chi^2(2) = 13.45$, $p = .001$, and the proportion of children's talk about exhibits and actions, $\chi^2(1) = 7.53$, $p = .006$, predicted significant variance in this model. We investigate this relation further in Chapter VI when we consider the specific timing between children's talk about the exhibit and the sequence of resolute behaviors.

Discussion

The objective of this chapter was to document the language spoken by parents and their children, both causal explanations and other kinds of talk that parents and children engaged in during their interactions. Although there were variations across sites in the types of language parents and children generated while interacting with the gear exhibits, there were consistent relations between the proportion of causal talk generated by parents by children at all three sites. There are many possible reasons for this similarity in language between parent and child, most notably that they are language partners in the same conversation and therefore may influence what each other say. The variation in causal language across families raises questions about whether the language children hear and engage in is related to their exploratory behavior (a possibility explored further in Chapter VI), or to their reasoning on causal tasks (a possibility explored in Chapter VII).

There were several interesting relations between the language generated during free play and children's exploration. Children's systematic exploration correlated with the proportion of parents' talk that was causal. Children's resolute behavior correlated with the proportion of children's own talk that was about actions or the exhibit. Various demographic factors were also related to the language used by parents and children. When looking at children's systematic exploration, we found that parents' causal talk, children's age, gender, and parents' educational level are all potential mediators. Indeed, when all of those variables were considered, the relation between parents' causal talk and children's systematic exploration was only marginally significant. When examining the relation between children's resolute behavior and their talk about actions and the exhibit, age and site were potential mediators, but their talk was still a significant predictor.

The analyses presented in the current chapter considered only the average proportion of language generated or the average proportion of behaviors of a certain type during the entire free play session. These analyses say little about the minute-by-minute interaction between language and exploration, or about the dynamics of how children explore and what they say or hear. In Chapter V, we consider overall parent–child interaction style, and in Chapter VI, we consider how exploratory behaviors and parent and child language unfold over time, as well as how overall parent–child interaction style relates to these dynamics.

V. Parent–Child Interaction Style

In the previous chapter, we examined the interaction between aspects of the language children heard or generated and their exploratory behavior. Here, we take a more holistic lens, capturing qualitative differences in the styles of interaction used by parent–child dyads, and asking how goals for the interaction are set by the dyad: Who is setting goals? How are those goals achieved?

In this chapter, we code the general style of parent–child interactions, focusing on who was directing the interaction, and examine how the dyad's interaction style was linked to the specific kinds of exploratory behaviors children generated, the language (and particularly causal language) that parents and children generated or heard, and the dynamics among these behaviors. In particular, we initially coded whether the interaction was directed primarily by the parent, by the child, or was jointly-directed. We examined how interaction style varied as a function of demographic factors such as the age and gender of child, as well as the gender, income, education, and ethnicity of the parent. We also examined whether parentdirected, child-directed, and jointly-directed interactive styles related to both individual characteristics of the exploration and explanation generated by the dyad during the free play, as well as the patterns in those behaviors.

Coding

Coding Scheme for Parent–Child Interaction Style—We coded the free play behavior at the exhibit between parents and children to characterize their overall style of interaction. Coders watched the video session of free play only, and made a judgment about what style best described the interaction. The codes for families' interaction styles were modeled after a parent–child interaction coding scheme developed by Fung and Callanan (2013). In Fung and Callanan's coding scheme, interaction styles were differentiated by whether parents took a more directive or guiding role, and whether caregivers were more hands-on or hands-off with museum exhibit materials. We adapted this coding system to fit with the interaction at the gear exhibit and assigned families to one of three mutually exclusive categories: parent-directed, child-directed, or jointly-directed. The coding scheme for parent–child interaction style can be found in Table 10.

Coding and Reliability—At each site, coders viewed the videos to make a judgment about the parent–child interaction style. This coding was independent of the exploration and language coding described in the previous two chapters and was performed by different coders. Coding at each site occurred after extensive practice coding of videos from each site by main coders. Coders were instructed to divide the entire video of the free play session into 30-s segments, and code the interaction during that 30 s on the basis of the above coding system. We then counted the number of segments in each category, and the dyad was given the majority category label. In the case of ties (e.g., six segments were jointly-directed and six segments were child-directed), coders were asked to choose which of the majority categories best described the interaction. Agreement was performed on the basis of this final determination.

In RI and TX, two coders independently coded a randomly selected 20% of the data. Agreement in RI was 90% ($\kappa = .84$). Agreement in TX was 86% ($\kappa = .83$). Disagreements were resolved through discussion with two of the authors. In CA, two reliability coders achieved inter-coder reliability on a random 20% of the data with a third main coder. Agreement was 95% ($\kappa = .93$) between the main coder and reliability coder 1, and 82% ($\kappa = .73$) between the main coder and reliability coder 2. After resolving disagreements between one of the authors and the main coder, the three coders each coded a portion of the remaining data.

Results

Patterns in Parent–Child Interaction Style—We first considered whether there were differences in interaction style among the three sites. The overall distribution of parent–child interaction styles, as well as differences based on children's age and both parents' and children's gender are shown in Table 11. The overall distribution of parent–child interaction differed across the sites, $\chi^2(4, N = 325) = 40.17$, $p < .001$, $\phi = .35$. In RI, there were relatively few parent-directed dyads, and more child-directed and jointly-directed dyads. In CA, there were fewer child-directed dyads, and roughly equal numbers of parent-directed and jointly-directed dyads. In TX, the majority of dyads were jointly-directed, with fewer of the other two types. The source of these different patterns may result from differences in the demographics of the museum visitors in each site.

Looking across sites, we examined whether parent–child interaction style varied with children's age, with parents' gender or children's gender, and with family ethnicity, family income, and parent education. Overall, there was a significant difference in children's age among the three groups, Kruskal–Wallis $\chi^2(2, N = 324) = 10.42$, $p = .005$, but this difference only held in the RI sample (see Table 11). Rank comparisons of the PCI styles were conducted using Dunn–Bonferroni post-hoc tests. This revealed that children in child-led dyads were older than children in parent-led dyads, $z = -3.22$, $p = .004$. The other two comparisons were not significant, parent-directed versus jointly-directed: $z = -2.10$, $p = .11$, jointly-directed versus child-directed: $z = -1.58$, $p = .34$.

There were no differences in parent–child interaction styles based on children's gender or parents' gender, either in the overall data set or any individual site (see Table 11). These variables were not considered further for this measure.

Variations in parent–child interaction style by ethnicity are shown in Table 12. The three largest self-reported ethnicity groups were Caucasian/ European-American, Latinx, and Asian/Asian-American. Considering just these three groups, there was a significant difference in the relative number of families coded as parent-directed, jointly-directed, and child-directed, $\chi^2(2, N = 189) = 17.09$, $p = .002$, $\phi = .30$. A larger proportion of Asian-American families were coded as using a parent-directed style, whereas a larger proportion of European-American and Latinx families were coded as jointly-directed. Because a large proportion of the Asian-American families participated in CA, it is possible that the site difference in parent–child interaction style was partly accounted for by this ethnicity difference.

In contrast to the variation by ethnicity, there were no significant differences in parent–child interaction style based on parents' education, Kruskal–Wallis $\chi^2(2, N = 309) = 0.28$, p = .87, or household income, Kruskal–Wallis $\chi^2(2, N = 288) = 2.42$, p = .30. There were also no significant differences in interaction style based on the frequency of families' museum visits, Kruskal–Wallis $\chi^2(2, N = 318) = 1.57$, $p = .46$, parents' attitudes about science, Kruskal–Wallis $\chi^2(2, N = 312) = 0.17$, $p = .92$, or parents' background in STEM, Kruskal–Wallis $\chi^2(2, N = 325) = 2.81$, $p = .25$,

Linking Parent–Child Interaction Styles to Exploration and Talk Measures— We next examined the relations among parent–child interaction styles and the types of exploration and parents' and children's language that were discussed in Chapters III and IV. We focused on parents' causal talk and children's talk about exhibits and actions, as these types of utterances were related to systematic exploration and resolute behavior respectively (as described in the previous chapter). Because there were significant differences in age for some of the relevant independent variables, we included age in these models. For each of these analyses, we constructed general linear models, specifying an ordinal logistic analysis on the proportion of systematic exploration and resolute behavior (defined in Chapter III) and parents' causal language and children's talk about exhibits and actions (defined in Chapter IV). We describe each of these analyses below.

For the proportion of systematic exploration, the overall GLM was significant, Wald $\chi^2(3) = 44.09$, $p < .001$. This analysis revealed significant main effects of age, Wald $\chi^2(1) = 27.64$, $p < .001$, and parent–child interaction style, Wald $\chi^2(2) = 12.92$, $p = .002$. Specifically, there was a greater proportion of systematic exploration on the part of children in jointly-directed dyads than parent-directed dyads, $\beta = .90$, SE = .26, Wald $\chi^2(1) = 12.39$, $p < .001$. Differences between the child-directed dyads and the other two groups were not significant.

For the proportion of resolute behavior, the overall GLM was significant, Wald $\chi^2(3) = 20.96$, $p < .001$. In this case, there was a significant effect of age, Wald $\chi^2(1) = 18.10$, $p < .001$, but not a significant main effect of parent–child interaction style, Wald $\chi^2(2) = 1.56$, $p = .45$. We did not consider the role of parent–child interaction style further in this analysis.

We next examined the proportion of parents' causal talk. Again, the overall model was significant, Wald $\chi^2(3) = 20.82$, $p < .001$, with a main effect of age, Wald $\chi^2(1) = 9.25$, $p = .002$, and a main effect of parent–child interaction style, Wald $\chi^2(2) = 15.56$, $p < .001$. In this analysis, parents in both parent-directed and jointly-directed dyads generated a greater proportion of causal talk than did parents in child-directed dyads, $\beta = 0.07$ and 0.05, $SE =$ 0.02 and 0.02, Wald $\chi^2(1)$-values = 13.25 and 10.50, $p < .001$ and $p = .001$, respectively.

Recall that in Chapter IV, we documented a relation between children's systematic exploration and the proportion of parents' causal talk. We further investigated this relation here by constructing a general linear model on the proportion of systematic exploration to consider the unique effects of age, parent–child interaction style, and the proportion of parents' causal talk. The overall model was significant, $\chi^2(4) = 45.35$, $p < .001$. There were main effects of age, Wald $\chi^2(1) = 25.01$, $p < .001$, and of parent–child interaction style, Wald $\chi^2(2) = 13.04$, $p = .001$, but not of parents' causal talk, Wald $\chi^2(1) = 1.24$, $p = .27$. Further analysis of the main effect of parent–child interaction showed that children in jointly-directed dyads generated a greater proportion of systematic exploration than children in parent-directed dyads, $\beta = 0.92$, SE = 0.26, Wald $\chi^2(1) = 12.77$, $p < .001$. The difference between the child-directed and parent-directed dyads was marginally significant, $\beta = 0.54$, $SE = 0.29$, Wald $\chi^2(1) = 3.38$, $p = .06$, with more systematic exploration in dyads that were child-directed.

Finally, for the proportion of children's talk about actions and the exhibit, the overall model was again significant, Wald $\chi^2(3) = 9.77$, $p = .02$. There was a significant main effect of parent–child interaction style, Wald $\chi^2(2) = 7.05$, $p = .03$, and a marginally significant main effect of children's age, Wald $\chi^2(1) = 3.40$, $p = .06$. The children in jointly-directed dyads generated a greater proportion of such talk than children in child-directed dyads, $\beta = 0.61$, SE = 0.23, Wald $\chi^2(1) = 7.03$, $p = .008$, but there was no difference between children in the child-directed and parent-directed dyads, $\beta = 0.43$, $SE = 0.28$, Wald $\chi^2(1) = 2.40$, $p = .12$.

In Chapter IV, recall that we documented a relation between children's resolute behavior and the proportion of children's talk that was about actions and the exhibits. To investigate the role of parent–child interaction style on this finding, we constructed a general linear model on the proportion of resolute behavior, considering the unique effects of age, parent–child interaction style, and the proportion of children's talk about actions and the exhibit. The overall model was significant, $\chi^2(4) = 24.74$, $p < .001$, and there were main effects of age, Wald $\chi^2(1) = 16.41$, $p < .001$, and children's talk about exhibits and actions, Wald $\chi^2(1) =$ 3.76, $p = .05$, but there was no main effect for parent–child interaction style, Wald $\chi^2(2) =$ 1.20, $p = .55$.

Discussion

The objective of this chapter was to document how parents and children generally interacted during the free play session, and how that interaction style might affect aspects of children's exploration and the language they and their parents generated. We used a holistic coding scheme to describe parent–child interaction style based on who was setting and accomplishing goals at the exhibit. Notably, to the extent that sample sizes allow us to consider ethnicity in subsamples of our population, overall parent–child interaction style varied by ethnicity. Future work should investigate this variation more systematically.

These data suggest that certain interaction styles were related to facets of children's exploration and both parents' and children's talk. When the parent–child interaction was primarily directed by the parent, children showed less systematic exploration than when the interaction was more collaborative and jointly-directed, or when it was primarily directed by the child. The parent–child interaction style described here explained more variance in the proportion of children's systematic exploration than the proportion of causal talk generated by the parent. In contrast, the parent's interaction style did not explain a significant amount of the variance in the proportion of children's resolute behavior; children's talk about their actions or the exhibit did. This kind of talk, and not parent–child interaction more generally, was important for children's persistence.

As mentioned in the discussion of the previous chapter, an important caveat is that we are analyzing summary statistics over the entire free play session. In Chapter VI, we investigate the dynamics in the timing of children's exploration and parents' and children's language as they explored the exhibits to provide a finer-grained analysis of how these behaviors relate to one another.

VI. Dynamics Among Children's Exploration, Parents' and Children's Language, and Parent–Child Interaction Style

The overarching objective of this program of research was to describe the dynamic interactions among the ways that children explore the gear exhibit and the ways parents and children talk to each other during that free play. In previous chapters, we have described children's exploratory behaviors, parents' and children's language, and the manner in which parents and children interact, as well as the interactions among these variables. Our focus so far has been on relations between time-invariant factors that might influence specific aspects of the free play between parents and children, such as the relations among children's exploration, parent's and children's language, parent–child interaction, and various demographic information about the family. The objective of this chapter is to describe findings from a sequential analysis of how exploratory behaviors unfold over time, and how language and interactions are related to these exploratory behaviors. This approach allows us to examine the complex patterns linking time-invariant factors to behaviors and talk that change over the course of parent–child free play.

There are numerous approaches to analyzing sequences of behaviors, one of which was used in Chapter III to examine the distributions of certain sequences of exploration. However, many of these analytical approaches are limited in their capacity to consider time-invariant data such as demographics or a holistic coding scheme like parent–child interaction style. Here, we used generalized linear mixed models (GLMMs) to examine how both time-invariant and time-variant factors interacted in predicting children's behavior. Our goal is to document how the different factors we have discussed in previous chapters interact dynamically during parent–child interaction.

These analyses start with the observation that exploratory behavior changes over time. In previous chapters, we focused on two sequences of behaviors we defined a priori as meaningful for exploratory analyses—*systematic exploration* and *resolute behavior*. We showed that the overall percentage of these behaviors correlated (or failed to correlate) with various demographic factors or with other aspects of parent–child activity and conversation while playing at the exhibit. In this chapter we document how these behaviors changed as free play unfolded, as opposed to just reporting total frequencies of such behaviors. Examining how these behavioral dynamics interact might relate to what children learn from these behaviors, the topic we discuss more explicitly in Chapter VII.

Moreover, we can analyze a particular difference among the sites. In CA, the gears exhibit was designed to communicate specific goals. Families were challenged to build gear machines that would spin gears visible behind Plexiglass so that they could achieve certain outcomes. For example, one gear behind the Plexiglass had a ballerina on it, and spinning that gear made the ballerina dance. By looking at just the CA data, we can examine whether systematic exploration differed if the action involved building a gear machine that was connected to one of these goals.

Similarly, in RI, we observed different patterns of resolute behavior, presumably because of the way the exhibit was designed (as a vertical pegboard instead of a horizontal magnetic table). To analyze resolute behavior, we focused on the sample of children from RI because analyzing the whole data set could have masked effects that were present when children were faced with challenges that required troubleshooting their own behaviors.

Modeling Dynamic Interactions

We used a GLMM with a logit link and random-intercepts, and leveraged robust standard errors to accommodate correlations between predictive errors. Because there were variant numbers of time intervals for each case, using AR1, ARIMA or other estimation techniques proved computationally overwhelming, and could be accounted for by using robust standard errors.

We divide the rest of this chapter into describing two sets of models, one for each of the two kinds of behaviors predicted to be important for learning a priori—systematic exploration and resolute behavior. For each, we articulate the nature of the analysis, comparisons among models, and what significant results indicate for children's learning. We chose to evaluate models using Bayesian information criterion (BIC) statistic because it more conservatively discriminates against overfitting with additional variables in a given model. However, in almost all cases, comparisons using the Aikake information criterion (AIC) statistic yielded identical results. We report the F-statistics for each variable's contributions to the corrected model to explain why we reject the null hypothesis that observed data were not different from the theoretical model, thus showing how each variable in the model predicted the outcome variable. The inclusion of reporting 95% confidence intervals (CIs) helped us determine how certain we could be that linear trends would occur in the population, given our sample (more specifically, whether zero was included between the lower and upper limits).

Systematic Exploration—Recall that our definition of systematic exploration during free play was children moving from a 5-s interval in which they explored a connection between at least two gears to a 5-s interval in which they explored by spinning (or attempting to) the machine that they had created. The GLMM analysis considers whether children are in an exploring gear machine segment (or an attempting to explore gear machines segment) given that the previous segment was exploring connections, in addition to simultaneously considering various other independent variables.

We considered three different models (shown in Figure 9) for cases in which systematic exploration took place, based on when parents' language occurred. In the *Lag* model, the parent's causal language started in the 5-s interval that was coded as the onset of the connection event (i.e., exploring connections).

The causal language occurred while the child was building a gear machine by connecting gears to one another, but prior to their spinning the machine. In the *Concurrent* model, the parent's causal language started in the 5-s interval where the child was coded as exploring machines (i.e., spinning the gears). In this model, the language occurred during the testing (spinning) of that gear machine. Finally, in the *Reactive* model, the causal language occurred in the 5-s interval after the initial testing, and thus could be seen as reactive to the child's exploration (although whether the parent specifically noticed the child's behavior was not captured in this coding system).

All three models included fixed variables such as site differences, parent–child interaction style (as described in Chapter V), children's age and gender, and several aspects of family background (parents' attitudes toward science, years of schooling, science background, and income). Causal language was coded as an indicator of whether the parent generated a causal utterance (as defined by the coding scheme in Chapter IV) at the particular time interval defined by the model. To be clear, causal talk and noncausal talk were contrasted within the same dichotomously coded variable; not as two separate time-variant variables, whose overall redundancy would result in a model that could not converge. In particular, we contrasted generating a causal utterance against the parent not talking as a way of testing whether not hearing any language was also a factor in predicting whether children would engage in systematic exploration.

The significance levels of this analysis and their model fits are shown in Table 13. The Lag model provided the best fit, according to both BIC and AIC. However, the three models were so close together in fit values that it is worthwhile to analyze them independently to see how the presence of causal language (or absence of any language) at particular times affected the likelihood of children's systematic exploratory behaviors.

Before analyzing each model individually, it is worthwhile to consider several commonalities among the models. First, in all three models, there is a significant effect of children's age. As children got older, they were more likely to generate systematic exploratory behaviors; and age uniquely predicted variance. Second, across the three models, there was a significant difference between the child-directed dyads and the parent-directed dyads, with less systematic exploration generated by parent-directed dyads. These findings are both consistent with our previously reported analyzes in Chapters III and V, respectively, when the analysis was only time-invariant.

In the Lag model, we are measuring the likelihood of systematic exploration when parental causal language occurred prior to the child exploring the machine (i.e., when they are connecting but not yet spinning the gears). In addition to the effects of age and parent–child interaction style, the presence of causal language on the part of the parent increased the likelihood of systematic exploration in the next time interval, $F(1, 11196) = 9.51$, $p = .02$. In contrast, in the Concurrent model (when the causal language occurs with the spinning of the machine, instead of with the connecting of the gears), causal language did not predict systematic exploration, F(1, 11283) = 0.51, p = .48. Instead, no talk on the part of the parent was predictive of children's spinning, F(1, 11283) = 4.23, p = .04. Further contrasting these findings, parents' language after the exploration of the machine (the Reactive model) had no significant relation to systematic exploration—either causal language, $F(1, 11102) = 2.20$, $p = .14$, or the absence of language, $F(1, 11102) = 0.19$, $p = .67$. In the Reactive model, when comparing the conditional probability of systematic exploration occurring given that children were exploring a connection, there were differences across sites (RI compared to CA, $F(1, 11101) = 5.65$, $p = .018$; and TX $F(1, 11101) = 4.41$, $p = .04$), as well as unique significant effects of parental educational level, $F(7, 11102) = 2.76$, $p = .01$, and science background, $F(1, 11102) = 8.19$, $p < .01$.

These analyses suggest that the dynamics of parental language—specifically at what point in time parents generate causal language during children's exploration—interacts with whether children engage in systematic exploration with the gears. When parents generated causal utterances while children were connecting gears together, children were more likely to explore the connections that they generated. In contrast, the benefit of causal language is not present when the language is concurrent to the exploration of the gear machine, nor is the benefit present if it occurs directly after the systematic exploration.

One way to interpret these findings is that it is not the overall amount of causal language that promotes systematic exploration, but rather causal language may be beneficial when children are engaging in a preparatory action to produce a causal connection. The Lag model suggests that exploring a connection enables children to produce novel gear machines, which then can be explored further. Parental causal language at this point during the play might promote children's engagement in those actions. In contrast, the Reactive model suggests that causal language in reaction to children exploring a machine might have a different function. It might serve to promote children's understanding of the machines or the causal structure (indicated by general relation between the proportion of parents' and children's causal language, as described in Chapter IV), but it is does not specifically encourage systematic exploration at that particular moment during the play. Similarly, the Concurrent model suggests that parents also might play a role in promoting exploration in another way—by *not engaging* with the child verbally when children are specifically engaging in their exploration of the machine.

The Reactive model also allows us to explain some of the correlations that we observed in Chapter III. In that chapter, we documented a correlation between parent's education level and children's systematic exploration. In the Reactive model, we observe a significant effect of parent's education level—and it is the only model we investigated in which this effect is present. That is, parental education level might relate to children engaging in systematic exploration, but not necessarily in the same way as the causal language children might hear from parents (even though there is a significant correlation between parent's education level and the proportion of causal language they generate).

Systematic Exploration With Goals—One major difference between the gear exhibit in CA versus the other two sites was that in the CA sample, children could engage in systematic exploration of two distinct types: (a) systematic exploration that built a machine connected to one of the goals in the exhibit that was visible behind Plexiglass or (b) systematic exploration of machines on the gear table without being connected to one of the visible goals. The presence of visible goals may influence parent–child interaction, as shown in an earlier study with proto-type versions of this same exhibit. That is, Fung and Callanan (2013) found that when the goal objects were visible, parents engaged in more directive interactions than they did when no goal objects were visible. An exploratory question was whether the relation between parents' language and children's exploration differed when the systematic exploration involved or did not involve connecting gears to one of the visible goals. To evaluate this possibility, we replicated our previous analysis on only the CA data, but added another factor, specifically whether the systematic exploration was related to spinning one of the goal-connected gears.

We ran similar Lag, Concurrent, and Reactive GLMMs on the data from the CA site, including as a factor whether the systematic exploration involved a machine connected to one of the goals of the exhibit (i.e., one of the three gears that were permanently housed in the exhibit behind Plexiglass that could be connected to with other gears on the table). The significance levels of this analysis and their model fits are shown in Table 14.

First, we discuss similarities among the individual models, then differences. In all of the models, there are significant effects of age, with older children generating more systematic exploration. There was also a significant effect of type of parent–child interaction, specifically with children in the parent-directed dyads generating less systematic exploration than children in child-directed dyads. These findings replicate the main analyses presented above.

The effect of causal language also replicates. In the Lag model, and not in the Concurrent or Reactive models, there is a significant effect of parents' causal language at that particular time during the free play. Notably, there was not a main effect of goal in any of the three models under consideration (Lag, Concurrent, and Reactive, see Table 14 for statistical analyses). Children did not generate more systematic exploration when building a machine connected to one of the three goal gears in the exhibit than when simply building gear machines on the gear table.

There are two differences in the analysis when only this sample is considered. The first is that unlike the previous analysis, there was a significant main effect of parental education level in each model (see Table 14), not just the Reactive one. Recall that the CA data set contained the most highly educated parents (the average education level was higher than a Bachelor's degree), which might have skewed this subset of the sample. The second was that in the Concurrent model, there was no significant effect of parents failing to talk, $F(1, 1823) = .08$, $p = .78$. Parents not talking during the time interval specified by the Reactive model, however, was significant, $F(1, 1860) = 9{,}969.69$, $p < .001$.

In sum, when we considered the CA sample alone including whether children were building machines connected to the visible goals, we replicated many aspects of the GLMM analysis on the whole data set. We replicated the effect of age, such that children engaged in more systematic exploration as they got older. We also replicated the significant effect of causal language predicting children's systematic exploration under particular conditions of timing. When parents used causal language while children were connecting gears, children were more likely to spin that gear machine (i.e., complete the sequence of behaviors we have referred to as systematic exploration). The effect of goal was not significant; in other words, the relation between the timing of parents' language and children's exploration was the same regardless of whether children were or were not building machines connected to the visible goals of the exhibit.

Resolute Behavior—Our final sequential analysis focuses on the relation between children's own language about exhibits and actions and their resolute behavior. As with systematic exploration, we constructed three models that looked at the dynamics of the relation between this language and action at different time intervals. In the Lag model, children generated their utterance during the 5-s interval when they attempted to explore the connection or the gear machine (i.e., while the child was encountering a problem). In the Concurrent model, the language occurred in the interval when the problem was resolved (e.g., the child connected the gear after having attempted to do so). Finally, in the Reactive model, the language occurred after the problem was resolved (in the next 5 s interval).

We constructed similar GLMMs examining Resolute Behavior as the dependent measure, considering children's age and gender, the time of the exploration in the free play and whether children generated an utterance about exhibits or actions, or did not talk at the time specified by the model (Lag, Concurrent, and Reactive). Initially, we examined these models for the entire data set. But performing this analysis proved problematic in two ways. First, we encountered numerous significant site differences. The RI site had greater frequencies of attempting behaviors than either of the other sites, based on the structure of the exhibit. We were concerned that the low frequency of these behaviors in the other sites would skew the results of the models, rending them nonsignificant. Indeed, this turned out to be the case, particularly for the Concurrent model, which was a nonsignificant model overall. As a result, we only analyzed the data from RI.

When we considered only the RI data set all of the models were significant overall. The results are shown in Table 15. Unlike our analysis of systematic exploration, we did not include many of the demographic variables that did not significantly correlate with children's resolute behavior or their talk about exhibits and actions. We also did not include the parent–child interaction style, as it was not related to the overall proportion of children's resolute behavior (as shown in the analyses in Chapter V). Thus, only children's age and gender, time during the play, children's language and the lack of talking were independent variables in this analysis.

The results of these models are more straightforward than the systematic exploration analysis. In all three models, age was a significant factor in predicting resolute behavior, with older children engaging in more such behavior. This was consistent with the general relation between age and resolute behavior, described in Chapter III. The time when children played during the free play was not a significant factor in any of the models. We had expected that as the play continued, children might have engaged in more resolute behavior after having figured out the affordances of the exhibit. However, it is also possible that any act of attempting to connect the gears together would provide children with the feedback necessary to understand that the gears would not always fit in the exhibit in the same manner (which might have been an exclusive feature of the RI exhibit).

In the Lag model, there was a significant effect of children's talk about actions during the interval when children were attempting to connect or spin gears, consistent with previous analyses. This variable was not significant in the Concurrent or the Reactive model. The absence of talk, however, was not a significant predictor in any of the models. These data suggest that children talking about actions while attempting an action was related to their resolute behavior at this particular point in time during their exploration. For example, it was related to their likelihood of succeeding at the attempted behavior in the following interval, but unlike systematic exploration, the absence of talk did not relate to that behavior at a later point during their play.

A possible interpretation of these results is that children's resolute behavior is not primarily socially mediated, but instead is motivated more by children's reflection on their own actions. When children encounter trouble in their exploration, they might treat the language that they generate as helping to resolve that trouble, but only if that language is generated at a particular time. In many ways, these findings are reminiscent of the "self-explanation effect" that we described in Chapter I (e.g., Chi et al., 1994; Lombrozo, 2006). The language that children generate to themselves might serve as an explanatory mechanism for the trouble they find with connecting or spinning the gears. Generating language that describes the exhibit or the action might facilitate resolving that trouble, thus acting like an explanation in problem solving.

Notably, we did not include parent–child interaction style as a predictor in the analyses of children's resolute behavior, as it was unrelated to the overall proportion of children's resolute behavior in our time-invariant analyses in Chapter V. We reran all of these analyses just presented in this section, but including parent–child interaction style. The significance levels of the other findings did not change from what is reported above. There was a marginal trend between the child-directed and parent-directed children (with child-directed children generating more resolute behavior, $p = .054$), but the model reported above has a better overall fit, as measured by BIC. This suggests that parent–child interaction style did not affect the dynamics of children's resolute behavior, again suggesting that this behavior might capture a more internal problem-solving process on the part of the child.

Discussion

In this chapter, we conducted several analyses that relate time-invariant with time-variant variables inherent to parent–child interaction. Our analyses revealed two main findings. First, when the sequence of behaviors was considered, specific dynamics between language generated by parents and actions generated by children resulted in more systematic exploratory behaviors (including goal-directed systematic exploration). We also observed that children's own talk about their actions and the exhibit at certain points in their exploration led to more resolute behavior. In both of these cases, the timing between language and exploration described by the Lag model was the only model that revealed effects of language. This suggests that in addition to the overall relations among behaviors documented in the previous chapters, there are particularly productive temporal dynamics to the interaction between explanatory and exploratory behaviors.

The second main finding is that our two behaviors of interest—systematic exploration and resolute behavior—reveal different dynamics regarding the social nature of parent–child interaction. Children's systematic exploration related to parent talk, thus the social interaction might be facilitating children's own exploratory capacities as a means of supporting their learning. Resolute behavior, in contrast, revealed less evidence of social influence. When children encountered trouble in their exploration, they were more likely to resolve it based on their own language as opposed to hearing language from another. In this study, children were interacting within a dyad, and their talk about actions might have been specifically marked for themselves or for their interlocutor. It is unclear whether the same dynamic would result if children were playing by themselves. This is a potential subject for future investigations.

The results presented in the current chapter speak to the interaction and temporal order of exploratory, explanatory, and interactive behaviors; however, they do not tell us anything about the relation to children's learning or knowledge of the exhibit. In the next chapter, we consider children's performance on follow-up learning measures as a way of describing their causal thinking about gears. We also consider how the ways in which children explore, hear explanations, and engage in parent–child interaction relate to their causal thinking. In Chapter VII, we consider the impact of behavior and language during parent–child interaction on children's memory of perceptual features of the gear stimuli, their understanding of gear mechanisms, their ability to reconstruct the gear machine, and their ability to generalize their understanding to construct a machine using new stimuli.

VII. Modeling Links Among Explaining, Exploring, and Children's Causal Thinking

So far, we have presented relations among explanation, exploration, and parent–child interaction style during free play at the gear exhibits. Children were also given a set of follow-up measures of causal thinking after their free play. The goals for this chapter are to describe children's performance on these follow-up measures and then examine whether there are links between those measures and the dynamics among the exploration, explanation, and parent–child interaction style that we have described in the previous chapters.

To do this, we first describe the follow-up measures and how we coded them. We used a set of tasks on children's understanding of gears that have been used elsewhere (Legare & Lombrozo, 2014; Willard et al., 2019). In addition to replicating several of the coding schemes used in these papers, we designed new coding schemes, particularly to examine children's causal thinking in their constructions. We then looked at how these measures cohered to pull out which of our coding schemes in these follow-up tasks related to causal thinking. We confirmed this via factor-analytic methods, and then constructed structural equation models that allowed us to test our hypotheses about how children's performance on these tasks are predicted by the exploring and explaining measures discussed in the Chapters III–IV. Moreover, these models allowed us to consider the ways in which individual differences in parents' backgrounds—particularly related to their interests in and exposure to science—related to how they interacted with their children during free play.

Follow-Up Gear Tasks—Coding and Results

Due to experimental error, four children were not given the follow-up tasks, and one child was not asked the mechanism question (described below), thus reducing the sample size slightly. One child wanted to stop participation after the mechanism task and four children wanted to stop participation after the reconstruction task.

Memory and Mechanism Tasks—Following Legare and Lombrozo (2014), the follow-up learning tasks began with the gear machine shown in Figure 3. After children were shown how this machine worked, they were asked two questions about it. In the *color memory* task, the researcher removed one gear and asked the child to point to the piece that will make the machine *look* like it did in the beginning (Figure 4). The five choices were all the same size, and varied only in color; the task is a noncausal measure that shows whether the child remembers the exact color of the gear that is missing. Children were coded with 1 for the correct choice (child points to the yellow gear) or 0 for incorrect (child points to a different gear).

In the *mechanism* task, the researcher removed another gear and then gave children a choice among five different gear pieces, only one of which would make the gear machine function correctly (Figure 5). The researcher asked children to point to the piece that will make the machine *work* like it did in the beginning. This task measures children's recognition of the shape and size of the piece that would fit the open spot and serve the causal function, despite being colored differently. Children's behaviors were coded 1 (*correct*—pointing to the medium-sized purple gear) or 0 (*incorrect*—pointing to any other piece).

There were no differences among the three sites for performance on either question, both $\chi^2(2, N = 320$ and 319, respectively) values <2.44, both *p*-values > .23, so we analyzed the data here as an overall group. Children responded correctly on the memory task 16% of the time ($M = .16$, $SD = .36$). Children responded correctly on the mechanism task 49% of the time ($M = .49$, $SD = .50$). In both cases, performance significantly correlated with age, $r_s(318) = .16$, $p = .003$ for the memory question, and $r_s(317) = .26$, $p < .001$ for the mechanism question. Performance on these two questions did not correlate with one another, $r_s(317) = .01$, $p = .87$.

We next examined the extent to which performance on either of these questions related to any of the demographic variables. There were no significant correlations between performance on these questions and children's gender, parents' gender, parents' schooling level, parents' household income, parents' science background, parents' Attitudes toward Science scores, or families' frequency of visits to the museum. There was a significant correlation between performance on the mechanism question and parents' age, $r_s(317) =$ 16, $p = .004$. Age of parent was not a factor in any previous analysis. We consider it as a factor in subsequent analyses in this section, but we suspect that this particular significant correlation is Type I error.

We next considered the relation between the memory and mechanism questions and several of the analyses presented in the previous chapters. Performance on these two questions did not significantly correlate with the proportion of systematic exploration children engaged in, nor did performance on either question differ among the three parent–child interaction styles. Performance on the memory question did significantly correlate with the amount of resolute behavior children engaged in, $r_s(318) = .15$, $p = .008$. This was not the case for performance on the mechanism question, $r_s(317) = .06$, $p = .29$. Performance on the memory question also significantly correlated with the proportion of causal language parents generated, $r_s(318) = .12$, $p = .04$. This was also not the case for the mechanism question, $r_s(317) = .05$, $p = .34$, and no other facet of parents' or children's language related to performance on either question.

Reconstruction Task—In the reconstruction task, children were presented with an entirely disassembled version of the gear toy (see Figure 6) and were asked to recreate it using all of the parts of the original mechanism so that it worked as it did previously. The purpose of this task was to gauge children's understanding of the causal mechanism of how gears work. In preliminary scoring, children were given one point for each gear that was placed correctly, resulting in a score between 0 and 5. Prior to any analysis, we inspected the distribution of these scores, and found that a score of 4 was rare (4% of the sample). Through consultation with a statistical expert, we surmised from this unusual distribution that children who reached the point of placing four gears correctly were faced with an easy final step with zero degrees of freedom. Because of this, receiving a score of a 4 was unlikely and children who performed well on the task typically had either three or five gears placed correctly. When children received a score of a 4, in fact, it suggested that they may not fully understand the causal aspects of the reconstruction task, and this score should not be considered more advanced than a score of 3.

As a result, we created four ordinal groups as follows: children who placed no pieces correctly were considered the lowest performers and given a score of 0; children who placed one or two pieces correctly were considered low-mid performers, and received a score of 1. Children who placed three or four pieces correctly were considered mid-high performers and given a score of 2. If children placed all five gears correctly, they were high performers and received a score of a 3. Note that the statistical analyses we report below for this ordinal scoring replicate if we use the original scoring system.

This ordinal reconstruction score was correlated with children's age in months, $r_s(317) = .48$, $p < .001$. None of the other demographic factors that we investigated (children's gender, parents' age and gender, parents' level of schooling, household income, and interest in STEM, as well as responses to the attitudes toward science questionnaire) significantly correlated with children's reconstruction score. Children's reconstruction scores did significantly correlate with their proportion of systematic exploration, $r_s(318) = .22$, $p < .001$, but not their resolute behavior or any facet of parents' or children's language.

To isolate the independent contribution of children's systematic exploration on children's reconstruction scores, we constructed a general linear model, assuming an ordinal logistic distribution on children's scores on the reconstruction task, looking at children's age and the proportion of systematic exploration children generated. The overall model was significant, $\chi^2(2) = 82.39$, $p < .001$, and both age and children's systematic exploration explained a significant amount of unique variance, Wald $\chi^2(1) = 60.76$ and 3.65, $p < .001$ and $p = .05$, respectively.

We next looked at children's scores on the reconstruction task as related to the parent–child interaction styles. Reconstruction scores did differ among the three parent–child interaction groups, Kruskal–Wallis $\chi^2(2) = 10.60$, $p = .005$. The child-directed group had the highest mean reconstruction score (1.75), followed by the jointly-directed (1.55) and then the parent-directed (1.23) groups. Simple effect analyses with a Dunn–Bonferroni correction revealed that the parent-directed group scored lower than the child-directed group, $z = -3.23$, $p = .004$ and the parent-directed group was marginally lower than the jointly-directed group, $z = -2.26$, $p = .07$; there was no difference between the jointly-directed and child-directed groups, $z = -1.41$, $p = .47$.

We again constructed a general linear model to consider the unique variance of parent–child interaction style on reconstruction score. The effect of age was again significant, Wald $\chi^2(1) = 65.63$, $p < .001$, and once age was controlled, the effect of interaction style was not significant Wald $\chi^2(2) = 4.04$, $p = .13$.

Finally, because children's interactions with the causal mechanisms of the gear toy increased across each subsequent follow-up task, we evaluated how the distribution of scores on the reconstruction task differed when considering performance on the memory and mechanism tasks. Reconstruction scores were significantly correlated with the memory task, $r_s(318) = .12$, $p = .03$ and with the mechanism task, $r_s(317) = .19$, $p = .001$. Neither of these correlations, however, indicated a significant amount of unique variance when we considered a general linear model of performance on the reconstruction task with age and performance on these two questions in the model, Wald $\chi^2(1) = 1.10$, $p = .30$ for the memory task, and $\chi^2(1) = 1.94$, $p = .16$ for the mechanism task.

Generalization Task—In the final task, children were given new gear toys and invited to build their own machine: "Can you build a new machine with these pieces? You can make it any way you want" (see Figure 7). We coded children's interactions with the gear toys, by observing video of children's behaviors and coding which pieces were placed where on the base of the toy. We also coded for behaviors such as grabbing, touching (piece to the base), and connecting. Gears were coded by numerals, for example, assigning large gears 1–3 and small gears 4–6 (see Figure 10). Placement positions on the base were assigned letter codes. Data from this coding scheme were used to create a continually updating status of the toy configurations throughout children's free play. These updating configurations allowed us to look not just at a sequence of behaviors, but also at how children's behaviors related to sequences of toy configurations they created.

Coders from the CA group took responsibility for coding videos of the generalization tasks at all three sites. This team of coders conducted a reliability set for 20% of the sample for the CA site Each pair of coders achieved acceptable reliability levels (κ values ranged from .73 to .79). Once videos were coded according to this alphanumeric scheme of piece and placement throughout the child's interaction with the gear toy, we had sequential data that could also be used to calculate summary statistics.

Coding of children's open-ended play with gear toys was used to calculate three indices of children's exploration that related to causal thinking and creativity. We first considered the number of total configurations created by the child, which we called *fluency*. Fluency relates to the complexity of the causal structures that children constructed during their play. We next calculated how many of those configurations were unique compared to all configurations created by the samples across all three sites. This provided a measure of *originality*, which relates to the extent to which children think creatively about building gear models. Finally, we calculated the number of constructions children built off the base, which we called *elaboration*. Elaboration was a way that children could test affordances of the gears and how they related to one another, before committing to place them on the base.

Fluency: The fluency score reflects the total number of gear configurations children placed on the base. For example, as children played with the gear toy, each piece that was added created a new configuration. Each new configuration (duplicated configurations were not counted) was tallied and counted toward the fluency score. This score correlated with age, $r_s(313) = .47$, $p < .001$. No other demographic factor significantly correlated with children's fluency. Fluency also significantly correlated with both the proportion of children's systematic exploration and the proportion of children's resolute behaviors, $r_s(314) = .27$ and .19, both p-values < .001, but not with any measure of language. Fluency also differed among the three parent–child interaction styles, Kruskal–Wallis $\chi^2(2) = 6.78$, $p = .03$. To consider whether each of these factors contributed unique variance, we constructed a general linear model with an ordinal logistic distribution on children's fluency scores to isolate the unique variance of age, parent–child interaction style, and the two types of exploratory behavior. This analysis revealed that age uniquely explained children's fluency in the generalization task, Wald $\chi^2(1) = 57.80$, $p < .001$. The proportion of children's systematic exploration also explained a unique amount of variance, Wald $\chi^2(1) = 4.04$, $p = .04$. The proportion of resolute behavior did not explain a unique amount of variance in this model, Wald $\chi^2(1) = 0.09$, $p = .76$, nor did the parent–child interaction style of the dyad, Wald $\chi^2(2) = 1.55$, $p = .46$.

Originality: The originality score reflected the percentage of unique configurations that children generated during their free play. That is, for each gear children placed or removed from the base, we coded whether the resulting configuration on the base was unique to their play. This score was represented as a percentage of original constructions. Similar to fluency, there was a significant correlation between this measure and children's age, $r_s(313) = .37$, $p < .001$, but none of the other demographic factors. There were also significant correlations between this score and the proportion of both systematic exploration and resolute behavior, $r_s(314) = .21$ and .17, $p < .001$ and $p = .005$, respectively, but none of the types of language generating during the free play. Moreover, there was a significant difference in these scores among the three parent–child interaction styles, Kruskal–Wallis $\chi^2(2) = 13.87$, $p = .001$. We again built a general linear model to isolate the unique variance of each of these factors. Only age was significant in the model, Wald $\chi^2(1) = 22.71$, $p < .001$.

Elaboration: The elaboration score reflected the number of gear machines that children built off of the base. This score potentially reflects children's testing of the affordances of the gears themselves without the size constraints presented by having to fit the gears onto the base. Again, there was a significant correlation between this measure and children's age, $r_s(313) = .24$, $p < .001$, but no association with any other demographic factor. There were also significant correlations between the elaboration score and the proportion of both systematic exploration and resolute behavior, $r_s(314) = .24$ and .20, both p-values < .001, but no correlations with any of the types of language generated during the free play. Finally, there was a significant difference in this score among the three parent–child interaction styles, Kruskal–Wallis $\chi^2(2) = 11.11$, $p = .004$. However, when we built a general linear model to isolate the unique variance of each of these factors, only age was significant in the model, Wald $\chi^2(1) = 9.98$, $p = .002$.

Relations Among the Follow-up Measures

To examine the relations among the six measures we have described from the follow-up tasks, we ran a principal component analysis to examine whether these results could be analyzed in terms of latent variables. We used a direct oblimin rotation to consider whether the extracted components covaried. Table 16 shows the correlation matrix among these six scores. The Bartlett Test of Sphericity on this analysis was $\chi^2(15) = 146.02$, $p < .001$, MSA = .60. The determinant of the correlation matrix was .63. These figures provide reasonable measures of collinearity, so that we could perform this analysis. We considered factors that resulted from an Eigenvalue of 1 or greater. This resulted in two factors, shown in Table 17. The first factor had an Eigenvalue of 1.84, and explained 30.61% of the variance. The second had an Eigenvalue of 1.02, and explained 16.94% of the variance.

From this analysis, we extracted two latent variables. The first (which explained the most variance) we call *Children's Causal Thinking*. It reflects performance on the mechanism question, and the three measures from the generalization task. The second, which we call *Children's Memory*, reflects performance on the memory question, and performance on the reconstruction task. While we initially conceptualized the reconstruction task as a measure of causal thinking, it loaded more with the memory measure, perhaps because it involves reconstructing a gear machine from memory. Investigation of Table 17 also shows that children's elaboration (the extent to which children built particular gear constructions off the base during the generalization measure) loaded on both components. We included this component with the Causal Thinking latent variable, because it involved building gear machines and seemed less related to memory, but subjected the variables to confirmatory factor analysis (see below) to ensure that the elaboration variable was best placed with this latent variable. (Omitting this variable does not change the significance levels reported here between the children's causal thinking latent variable and other factors).

Structural Equation Models—Predicting Children's Causal Thinking

Structural equation modeling (SEM) techniques allowed us to provide an overview of how our measures work together to explain links among: (a) what background and experiences parents brought to the exhibit; (b) how children and parents interacted while at the exhibit; and (c) what approaches children took when independently exploring a toy similar to the exhibit they had just experienced.

To understand how explaining and exploring during parent–child interactions may influence the development of children's causal thinking and memory, we needed to establish a model that integrates our ideas about how the parent and child measures in our study interrelate. The design of our study was intended to examine the possible impact of explaining, exploring, and parent–child interaction style on two latent variables: *children's causal thinking,* and *children's* memory, which are reflected by our follow-up measures. Moreover, we posited a third latent variable: parents' interest and experience with science based on several demographic variables. We hypothesized that this latent variable might have influenced the explaining, exploring, and parent–child interaction styles observed at the exhibit.

We built a structural equation model to represent these potential impacts in an effort to understand how parents' science attitudes and background contributed to parent's causal language, children's systematic exploration, and the parent–child interaction at the exhibit, and how the experiences of both children and parents at the exhibit contributed to children's causal thinking during follow-up tasks with a gear toy.

Model Design—Our model sought to provide a broad overview for all of the measures, when analyzed, that contributed insights on the research questions posed by this study. The nature of SEM allowed us an opportunity to combine numerous measures as latent variables, estimating an underlying factor that contributes to the performance across different measures, rather than analyzing individual relations between variables more independently.

We included three latent variables in the model. The first latent variable is *Parents' Science Interest and Expertise*. This factor combines parents' attitudes toward science, parents' science background, and parents' schooling level. The remaining two latent variables are based on children's performance on the follow-up measures. As suggested by the principal component analysis above, these have been divided into *Children's Memory* and *Children's Causal Thinking*. *Children's Memory* is a combination of the scores on the memory task and the reconstruction task. *Children's Causal Thinking* is a combination of mechanism task scores and the three measures from the generalization task. The variance of each latent variable was set to 1 (i.e., unestimated) to allow us to test significance on all factor loadings. Though latent variables are typically calculated from at least three measured variables, only two measured variables were available for *Children's Memory*. This estimation was still possible due to the additional degrees of freedom provided by the other measured variable in our model. Missing data were accounted for using a full information maximum likelihood estimator.

Unlike the analyses in Chapters V and VI, in the analyses reported in this chapter, parent–child interaction style was included in these models as an ordered category with the ordered levels from parent-directed (lowest) to child-directed (highest). In Chapters V and VI, parent–child interaction style was treated as an unordered multinomial category. When interaction style was included in the SEM as an unordered category (multinomial), however, the model failed to converge on a solution. Given the number of observed and latent variables in our SEM, this is un-surprising. A limitation of this analysis strategy is that the more variables posted in the model, the more difficult it is to get the model to converge, particularly as the number of variables representing unordered categories increases. Treating parent–child interaction style as an ordered category does allow the model to converge, and is justified given that the parent-child interaction styles range meaningfully from low to high in terms of the degree of children's involvement in setting goals for the activity.

Confirmatory Factor Analysis—First, we ran a confirmatory factor analysis on our three latent factors (Figure 11) with the sample of 325 children across the three children's museum sites. This model showed good fit across all measures, Yuan–Bentler $\chi^2(24) = 49.56$, $p = .002$; Robust comparative fit index (CFI) = .92; Robust root mean square error of approximation (RMSEA) = .054, 90% CI [.032, .076]; standardized root mean squared residual (SRMR) = .047. While the χ^2 fit statistic did not quite meet the threshold (>.05) for goodness of fit, RMSEA and SRMR both indicated good fit of this model.

Parents' attitudes toward science, $\lambda = .47$ (95% CI = [.35, .60]), parents' level of schooling, $\lambda = .56$, CI = [.43, .69], and their background in science, $\lambda = .80$, CI = [.64, .95] all showed high loadings onto the *Parents' Science Interest & Expertise* latent variable, which suggests a good estimation of this variable. The two other latent variables (*Children's Causal Thinking* and *Children's Memory*) were also estimated. Though all measured variables significantly loaded onto these latent variables, the factor loading for mechanism task and generalization fluency on *Children's Causal Thinking* (mechanism score, $\lambda = .23$, 95% CI [.10, .36], $p = .001$; generalization fluency, $\lambda = .27$, 95% CI [.14, .40], $p < .001$) were not as strong in comparison with the other two predictors (generalization elaboration and originality). Similarly, the factor loading for memory task on the Children's Memory variable was also not as strong ($\lambda = .22$, 95% CI [.02, .41], $p = .03$) in contrast to the reconstruction task. Finally, there was a significant correlation between *Children's Memory* and *Children's Causal Thinking*, $\lambda = .50$, 95% CI [.11, .89], $p = .01$, but no significant correlation between *Parents' Science Interest* and *Expertise* and either of the other latent variables.

SEM Model Fit Statistics—The initial model (Figure 12) was fit on the sample of 325 children but showed only moderate fit, Yuan–Bentler $\chi^2(47) = 125.96$, $p < .001$; CFI = .75; RMSEA = .076, 90% CI [.060, .093]; SRMR = .064. Some additional significant correlations among observed factors were added to the model to improve the overall model fit. This is a standard practice in SEM; fit statistics in these models compare the variance explained by the model to the variance in the data. This means that if any existing relations in the data are not accounted for by the model, the model will not fit. Given that these relations were not a priori predictions, they were included as correlations rather than directional paths. Specifically, we added in correlations between parent–child interaction style and parent causal talk, $\lambda = -.38$, 95% CI [−.47, −.28], $p < .001$, children's systematic gear exploration and parents' causal talk, $\lambda = .17$, 95% CI [.07, .27], $p < .001$, generalization fluency and originality, $\lambda = .32$, 95% CI [.15, .49], $p < .001$, and generalization fluency and elaboration, $\lambda = -.23$, 95% CI [−.45, −.000], $p = .05$. These additional correlations give the model a better level of fit on all metrics, Yuan–Bentler $\chi^2(43) = 74.38$, $p = .002$; CFI = .93; RMSEA = .046, 90% CI [.028, .063]; SRMR = .046.

The *Parents' Science Interest & Expertise* variable was significantly predictive of parents' causal talk at the museum exhibit, $\lambda = .15$, 95% CI [.02, .28], $p = .03$, but not parent–child interaction style or children's systematic exploration. Children's systematic exploration and parent–child interaction style were significant predictors of *Children's Causal Thinking* (systematic exploration, $\lambda = .38$, 95% CI [.23, .54], $p < .001$; parent–child interaction, $\lambda = .21$, 95% CI [.04, .38], $p = .02$) and Children's Memory (systematic exploration, $\lambda = .33$, 95% CI [.11, .55], $p = .003$; parent–child interaction, $\lambda = .24$, 95% CI [.01, .47], $p = .05$). Parents' causal talk predicted neither latent variable.

Including Age and Gender in the Model—Because children's age and gender have been important predictors throughout our analyses, we ran a second model with these variables included (Figure 13). Both children's age and gender were added as predictors of children's systematic exploration, parent–child interaction style, parents' causal talk, *Children's Causal Thinking*, and *Children's Memory*. This model showed good model fit, Yuan–Bentler $\chi^2(57) = 88.59$, $p = .005$; CFI = .92; RMSEA = .041, 90% CI [.023, .058]; SRMR = .041. Children's age significantly predicted all variables except parents' causal talk and *Children's Memory*. Children's gender predicted only children's systematic exploration, $\lambda = -.18$, 95% CI [−.28, −.08], $p < .001$.

The inclusion of age and gender did impact some of the other effects. Children's systematic exploration remained a significant predictor of *Children's Causal Thinking*, $\lambda = .19$, 95% CI [.03, .33], $p = .03$, but parent–child interaction style did not, $\lambda = .12$, 95% CI [−.03, .28], $p = .12$. Neither variable, in contrast, remained a significant predictor of *Children's Memory* (systematic exploration, $\lambda = .13$, 95% CI [−.04, .32], $p = .12$; parent–child interaction style, $\lambda = .15$, 95% CI [−.03, .30], $p = .11$. Given the additional posited connections in this model, the sample size was too small to make appropriate conclusions about the specific role of age and gender (as indicated by relatively high, but nonsignificant correlations in certain parts of the model). While this model solidifies the relation between children's systematic exploration and their causal thinking, independent of age, the unique contribution of the parent–child interaction style to children's causal thinking might have a smaller overall effect. We return to this discussion in the next chapter as we integrate this SEM model with our GLMM analysis from Chapter VI.

Discussion

Our follow-up measures examined children's causal thinking about gears. Using principal component analysis, we suggest that some of these measures center around children's memory for causal structures while others reflect their causal thinking while interacting with the gear exhibit. Our follow-up measures were limited by the age of our participants. There are certainly other types of knowledge one can learn about gears, such as understanding that connected gears must spin in opposite directions and that the speed with which a gear spins is related to the size of the gear (Dixon & Bangert, 2004; Lehrer & Schauble, 1998). Here we investigated only 3- to 6-year-olds; the younger age range we worked with here better reflects the ages at which children may begin to interact with these museum exhibits. Examining the extent to which interaction between parents and children at a museum promote discovery of these more advanced causal principles would be a compelling topic for future research.

What we examined were links from the operationalizations of children's systematic exploration, parent–child interaction style, and parental causal language that we have previously described, to metrics of causal thinking based on how children reasoned about gear placements and constructed novel gear machines on their own. The SEM in this chapter provides an informative analysis of our data set, given our goals to better understand how children's causal thinking may benefit from their experiences explaining and exploring with their parents at a museum exhibit.

Asking whether parents' background and attitudes linked with the dyads' talk and action at the exhibit, we found that parents' science attitudes and expertise predicted their causal talk to their children. Parents' causal talk, however, did not significantly relate to children's causal thinking. Asking whether explaining and exploring at the exhibit predicted children's performance on the follow-up tasks, we found that children's systematic exploration predicted their causal thinking in our base model. We similarly found parent–child interaction style related to children's causal thinking in this model. When children's age and gender were added to the model, the relation between systematic exploration and causal thinking remained significant. Other relations did not remain significant, but adding these two variables (and all of the relations they convey among factors) potentially weakens the overall predictability one can have from SEM analyses given our sample size.

The SEM analysis, like the analyses in Chapters III–V, considers only time-invariant measures. Combining these analyses with the GLMM analyses in the previous chapter, there is clear importance of both time-invariant and time-variant metrics. When parental causal language occurs and how parents and children interact in terms of goal setting both play significant roles in whether children engage in systematic exploration. In the final chapter, we discuss the implications of integrating these analyses and the relation between this synthesis and the theoretical constructions we introduced in Chapter I.

VIII. General Discussion

Overview

Our objective was to examine the relations between children's exploration, explanation, and causal thinking in the context of parent–child interaction at gear exhibits in three children's museums. We began with the theoretical assumptions that (a) there are dynamic and bidirectional relations between children's exploration and explanation, and (b) children's social partners (including parents and caregivers) are active collaborators in children's learning. We took an empirical approach to integrating constructivist and sociocultural approaches to the development of causal thinking.

In this closing chapter, we begin with a summary of our key findings, framed around the three main research questions we posed in Chapter I. We remind the reader how we addressed each question and summarize and interpret the findings. Next, we consider the significance of our results for theory, future research, and practical questions about supporting children's causal thinking. Regarding theoretical implications, we return to our focus on the integration of constructivist and sociocultural approaches to children's causal thinking that we proposed in Chapter I. Regarding implications for research, we discuss the impact of our findings for the development of causal thinking, and we consider benefits gained by our strategy of combining data from multiple sites. Regarding implications for practice, we address questions about fostering children's learning through play and everyday parent–child interaction in informal learning environments.

Brief Review of Key Findings

Exploring, Explaining, and Parent–Child Interaction Style—Our first research question involved considering relations among children's and parents' exploration, explanation and parent–child interaction while playing at the gear exhibits. We addressed this question in two ways: by looking at time-invariant behaviors in Chapters III–V, and then by looking at the relations among those behaviors as they occurred in time in Chapter VI.

In Chapter III we presented data on children's exploration. By coding children's exploration in 5-s intervals, we captured the most common behaviors, including exploring an individual gear (behaviors that tended to decrease with age), connecting gears (which tended to increase with age), and spinning gear machines together (which also increased with age).

We also defined two sequenced behaviors a priori that we thought would reflect important patterns of children's exploratory behavior. The first was systematic exploration of the gears—defined as sequences in which children begin with a 5-s interval in which they connect or disconnect gears to a machine, followed by an interval in which they spin gears. Systematic exploration reflected children's focus on the gear machine they were constructing and its causal efficacy. We hypothesized that this pattern of behavior related to children's causal thinking about the way gears interact. The second was resolute behavior —defined as sequences of exploration where attempts to connect or spin are followed by successful connecting or spinning, respectively. Resolute behavior reflected the extent to which children would persist in a behavior to accomplish a particular goal during their exploration. We hypothesized that this pattern of behavior related to the extent to which children troubleshoot in their exploration. Systematic exploration and resolute behavior both increased with age, supporting the proposal that they capture increasingly sophisticated exploration. These two exploratory behaviors also correlated with one another, and did so in a way that was not explained simply by their relation to age. These initial findings supported our decision to build our more complex analyses on the proportion of children's engagement captured by these two variables.

Moving to our talk measures, in Chapter IV, we described the language generated by both parents and children during their interactions at the exhibits. Our coding system divided talk into the following categories: causal talk, talk about actions and the exhibit, and other forms of talk. Not surprisingly, the proportion of parents' causal talk and children's causal talk correlated with one another—the larger the proportion of causal talk generated by parents, the larger the proportion of causal language generated by their children. This result could reflect the fact that topics under discussion were shared by conversational partners. The proportion of causal language generated by the parents was also related to children's age (older children had parents who generated more causal language) and to parental schooling level and science background, as measured by their background in STEM. The proportion of causal language parents generated during free play also correlated with children's systematic exploration, but this correlation was mediated by children's age, children's gender, and parents' level of schooling. Children's resolute behavior, in contrast, was unrelated to parents' causal language (or causal language in general), but was related to the proportion of language children themselves generated about exhibits and actions. This correlation held, controlling for age and other mediating factors.

Adding parent–child interaction style to the picture, in Chapter V, we examined the relations among children's exploratory behaviors, parents' and children's language, and the overall way in which parents and children interacted. We used a holistic coding scheme to document who set and accomplished goals during the interaction. We categorized parent–child interaction style in the following categories: parent-directed in which parents primarily set the goals for the interaction and/or completed actions, child-directed in which children set and accomplished their own goals and parents were more hands-off, and jointly-directed in which goals were set and achieved collaboratively. Children in jointly-directed dyads generated more systematic exploratory behavior than children in the other parent–child interaction styles. We did not see a similar pattern for children's resolute behavior. This behavior was unrelated to parent–child interaction styles. Regarding language, children in child-directed dyads had parents who generated less causal language than the other children in the sample, but overall few relations between parent–child interaction style and language were found.

All of the findings from Chapters III–V considered time-invariant factors, or relations among summary statistics over the free play session. Our approach in Chapter VI was to use sequential analysis of the two types of exploratory behaviors as they unfolded during free play. We investigated their relation to language, parent–child interaction style, and other potentially relevant demographic factors. By capturing exploratory behaviors at the level of 5-s intervals, our method allowed us to consider not only links across frequencies and proportions of explaining and exploring behaviors, but also patterns across time. An important contribution of this analysis is the unique opportunity to investigate the temporal dynamics of how explaining and exploring interrelate within these parent–child interactions. The sequential analysis we conducted using general linear mixed models revealed that parents' causal talk was part of a subtle temporal pattern predicting systematic exploring at particular moments in time. We found that when parents generated causal language during the same time segments when children were connecting gears, this predicted that children would next explore the spinning function of those gears in the subsequent time segment. This suggests that parents' causal talk may serve a potential scaffolding function when generated during particular moments of the interaction. Similarly, children scaffolded their own resolute behavior with language, but only when it was generated at particular times in the exploratory sequence.

Notably, these analyses allowed us to consider when differences among the sites were important or not. For example, in our analysis of children's exploration, children at Providence Children's Museum (RI) generated more attempts to connect gears than children in the other sites, presumably due to the nature of the different exhibit designs. This resulted in differences in resolute behavior among the three sites, and our focus on only the RI data set in Chapter VI. In contrast, the main analysis that we focused on—children's systematic exploration and its relation with parents' causal language and parent–child interaction style—did not reveal significant differences among the sites. Site was not a significant factor in the more dynamic analyses presented in Chapter VI. Whereas the frequency of different types of individual behaviors might differ across the three sites in our sample, then, the general pattern of dynamic interaction relating exploration, explanation, and parent–child interaction style was consistent across all subsets of our data.

Linking Exploring, Explaining, and Parent–Child Interaction Style to Family Characteristics—Our second research question was how contextual factors such as parents' science background, attitudes toward science, educational background, ethnicity and income were related to measures of exploring, explaining, and parent–child interaction style. We consider these measures in turn, asking whether parent characteristics predicted any of the patterns in families' interactions.

Parent Characteristics and Exploring: In our analyses of children's exploration in Chapter III, we found few links between parent or family variables and measures of children's systematic exploring or resolute behavior. This is further supported by the results of the structural equation model in Chapter VII, where the latent variable of parents' science interest and background did not predict children's systematic exploration. Moreover, in our GLMM in Chapter VI, parents' level of education and their background in science did not relate to systematic exploration in the Lag or Concurrent models. However, these variables did predict sequences of systematic exploration in the Reactive model. Because this finding involved both explanation and exploration, we elaborated on it in the next subsection.

In the analysis of systematic exploration involving goals at the exhibit (with only the data from Children's Discovery Museum of San Jose [CA]), parents' level of education was relevant for all of the models, not just the Reactive model. Whether children were connecting a gear towards one of the goal gears, however, was not a significant factor.

Otherwise, this analysis replicated the findings of the overall dataset. Parents' causal language related to systematic exploration only in the Lag model, where it occurred when the child was connecting gears.

Finally, there were relatively few family demographic factors that were related to children's resolute behavior, and the language that seemed to relate to this behavior was generated by the child, not the parent. While these null results are not conclusive, the relative absence of parent characteristics as predictors suggest that it is possible that children's tendency to troubleshoot problems while exploring the exhibit is relatively consistent across museum visitors from different backgrounds. While there was more resolute behavior in one of the sites (Providence Children's Museum [RI]), we suspect that this was due to the design of the exhibit, and not a limitation to one aspect of the sample.

Parent Characteristics and Explaining: In our analyses of parents' and children's language in Chapter IV, we found several links between parent or family variables and how parents and children talked during their play at the exhibit. In particular, several aspects of parents' background predicted their use of causal language in the exhibit setting. Specifically, parents with higher levels of education, and higher levels of STEM educational background, used more causal language with their children. These correlational findings are further supported by the structural equation model in Chapter VII, where the latent variable of *parents' science interest and expertise* predicted parents' causal talk in the exhibit. This result is also consistent with prior work considering links between parents' education or income level and the ways that they talk to their children (Kurkul & Corriveau, 2018).

In our GLMM analysis in Chapter VI, parents' level of education and their background in science were related to systematic exploration in Reactive model, but not in the Lag or Concurrent models. In other words, parents with more education and more of an educational background in science were more likely to engage in causal talk in segments just *after* children had completed a systematic exploration sequence. In contrast, parents' causal talk as children were beginning to engage in connecting gears, which was predictive of their transition to systematic exploration (the Lag model), did not vary by parents' education or science background.

These results suggest that parents' use of explanations at different times might have two distinct outcomes for children. First, causal language presented while children have the opportunity to explore the causal connections that they have just created may constitute co-construction of meaning, and may facilitate children's causal thinking, consistent with previous research by Willard et al. (2019). Second, causal language presented after children have engaged in the exploration of the structure that they have created may reflect parental recognition of the causal relations in the exhibit. The act of recognizing and being engaged by these causal actions after the fact might be what is related to parents' education, but based on our findings, we do not have evidence that this pattern is relevant to the development of children's causal thinking. What is important here is that sometimes parents generate causal language at times when there is an opportunity for the explanation to promote systematic causal actions, and this timing pattern of talk and action was not predicted by parents' educational background.

Parent Characteristics and Parent–Child Interaction Style: In our analyses of parent–child interaction style in Chapter V, we found several links between parent or family variables and the ways in which parents and children interacted during play at the exhibit, particularly in terms of who was setting and accomplishing goals. Parent–child interaction style was not correlated with parents' gender or household income, nor was it correlated with parents' attitudes toward science, schooling level or background with STEM. Consistent with these latter nonsignificant findings, the latent variable of parents' science interest and expertise did not predict parent–child interaction style in the structural equation model in Chapter VII.

There were, however, significant differences in parent–child interaction style related to self-reported ethnicity. Relations to self-reported race and ethnicity could account for some of the differences we observed among the three sites, as each museum had different patterns of diversity within their participant samples. As described in Chapter V, Asian-American families were more likely to be coded as using a parent-directed style, whereas Latinx and European-American families were more likely to use a jointly-directed style. This finding connects with other research comparing Asian and Asian-American parenting with European-American parenting. Some studies have shown a tendency toward more authoritarian or directive styles of parenting in Asian homes, and yet the findings are much more complex and nuanced than often assumed (Chao, 2001; Chao & Tseng, 2002; Leung, Lau, & Lam, 1998; Vinden, 2001). It is important to recognize that variations in parenting styles represent variations in cultural values about what it means to be a good parent (Gaskins, 2008a, 2008b; Heyman, Hsu, Fu, & Lee, 2013; Lancy, 2016), and that similar parenting styles can predict different outcomes in different cultural communities (Chao, 2001; Chao & Aque, 2009).

Our investigation was not specifically designed to examine differences among families of different ethnicities regarding parent–child interaction. There are also inherent challenges in designing such studies, as comparing diverse groups tends to encourage deficit-like comparisons that hold up white middle-class samples as the norm, as well as problematic assumptions that culture is a variable to be manipulated and controlled (Gutiérrez & Rogoff, 2003; Medin, Bennis, & Chandler, 2010). Moreover, given the holistic nature of the parent–child interaction style coding, it is possible that the ethnicity or race of the coder(s) may also affect the ways in which they interpret the interaction between parents and children of the same and of different backgrounds. This adds to the challenge of studying how parent–child interaction might differ across racial and ethnic groups. While it may be worthwhile to consider what mechanisms underlie potential cultural differences, it is perhaps even more important to recognize that cultural variations often highlight diverse paths to similar outcomes, such as children learning about causal mechanisms.

Linking Explaining and Exploring to Children's Causal Thinking—Our third research question investigated how patterns of exploration, explanation, and parent–child interaction style related to children's causal thinking via a set of structured follow-up learning measures. These follow-up measures were based on a previously published investigation of children's understanding of gears (Legare & Lombrozo, 2014). We replicated the basic procedure of this investigation and the scoring for the memory and mechanism questions, but constructed novel ways of scoring the reconstruction and generalization measures. The reconstruction measure focused on how many gears children could remember and reposition. The generalization measure, which was a measure of children's free play by themselves with novel gears, focused on their fluency with the gears (a measure of the complexity of their building), the originality of their play (a potential measure of how creative they were with gear construction), and their elaboration of play (a measure of how often they constructed gear pairs off the base). An important step in our analysis was a principal component analysis, which revealed two particular groupings among these measures (*Children's Causal Thinking* and *Children's Memory*), which were confirmed by a factor analysis.

We then investigated links among overall patterns of systematic exploration, parent causal language, and parent–child interaction style as they were predicted by individual differences in family characteristics, and as they predicted the follow-up task measures. Our confirmatory factor analyses suggested that the three latent variables we posited were all well-explained by our measures. In the initial SEM model (Figure 12), parents' interest and experience with science predicted the proportion of causal language they generated during free play, but not children's systematic exploration or the nature of the parent–child interaction style. Systematic exploration and parent–child interaction style were related to the two latent variables we constructed from the follow-up measures (*Children's Causal Thinking* and *Children's Memory*). Parents' causal talk, however, did not relate to these measures.

We then ran a second SEM model that included children's age and gender, as these variables predicted unique variance in our measures throughout the monograph. That model (shown in Figure 13) introduced many more paths into the model, and given the explanatory power of age, reduced the overall explanatory power of the parent–child interaction style on children's causal thinking. Children's systematic exploration, however, remained significant, even in the full model described in Figure 13.

Previous work from our laboratories (Willard et al., 2019) examined the relation between children's play at a gear exhibit and the same gear outcome measures used here. In our previous work, parents were randomly given conversation cards that prompted them to encourage their children to either explore the exhibit or to explain information about the exhibit. In general, the conversation card method affected behavior at the exhibit. Parents who were instructed to encourage their children to explore had children who explored the exhibit more (as measured by just the amount of time spent playing at the exhibit in certain ways). Parents who were encouraged to get their children to explain more asked more questions and produced more causal utterances overall. In turn, their children also produced more causal language. Notably, the conversation card manipulations did not relate to performance on the outcome measures, nor did the individual differences in parent–child interaction we measured in that paper. Our goal here was to look at parent–child interaction under more naturalistic settings, thus we did not provide parents or children with any explicit instruction. Moreover, the coding schemes we used here are more detailed, which potentially explains some of the differences between the findings we have detailed in the monograph compared with our previous study—particularly the relation between children's exploration and parental language at the exhibit and children's performance on the gear outcome measures.

Implications of Our Findings for Theory, Research, and Practice—Moving beyond the summary of our main findings, we now turn to a discussion of the implications of our findings. We consider in turn the potential impact of the findings for the theoretical goal of integrating constructivist and sociocultural perspectives, for contributing to the knowledge base of research on the development of causal thinking, and for practical implications involving supporting children's causal thinking in informal learning settings.

Integrating Constructivist and Sociocultural Theories—Our goal of integrating constructivist and sociocultural theories begins with our original discussion of how these approaches frame the relation between children's interaction with the world and their cognitive development. As we stated in Chapter I, constructivist theories focus on the way in which children process information from the environment to form representations of the world. On this view, the development of causal thinking is the function of algorithms that integrate exploratory and explanatory behaviors to create and revise an internal representation of causal knowledge. Sociocultural theories, in contrast, emphasize the social context in which causal information is explored and interpreted. Knowledge is not represented in an individual mind as much as it is co-constructed within activity. By integrating these two theories, we argue that children participate in shared meaning-making while interacting with parents and with objects (or exhibits in this case), that development occurs within these social interactions, and that children's cognitive representations are grounded in these social conversations and activities.

At its core, a constructivist interpretation of our results is that although parents can facilitate children's systematic exploration, it is the exploration itself that relates to children's causal thinking. Children observe the results of their actions and in doing so, come to learn more about the world. By presenting causal language at certain points in time during this exploration, parents encourage children to collect or interpret data in particular ways to support causal thinking. The ways in which children learn and engage in causal thinking, however, are internal to the child and part of the child's cognitive development. In particular, in Chapter VII, we observed that children's systematic exploration related to their causal thinking. Ostensibly, one might take only a constructivist interpretation of these data—the way in which children explore the world relates to the way in which they interpret and think about the world.

But our results suggest that the story is more complicated than just the constructivist interpretation outlined above. Children's systematic exploration relates to their causal thinking, but systematic exploration is also related to the dynamics among children's age, their parent–child interaction style, and when in their exploration they hear causal language (as shown by the GLMM analysis in Chapter VI). Parent–child interaction styles and parental language in the aggregate might not relate directly to children's causal thinking, but they do so through the dynamics of how children systematically explore their environment with their parent. Put another way, it is important to consider the nature of the interactions children and parents are having that facilitate the systematic exploration that relates to our measures of children's causal thinking. At many points during the free play, children might engage in the behaviors that would lead to the start of a systematic exploration. What seems to matter—as we suggest in Chapter VI—is the timing of parents' causal language. Children's behavior is supported by exacatly when they hear causal language.

In particular, the GLMM analysis in Chapter VI tells us that causal talk on the part of the parents, when well-timed with children's exploratory actions, might create shared opportunities to co-construct meaning or help children generate particular kinds of interpretations of their own actions. Viewed from this more sociocultural lens, co-constructed meaning in action is a setting for children's learning and development. Even though the overall proportion of causal language parents generate during the free play does not relate to children's causal thinking, the dynamics of that causal talk in synchrony with children's exploratory behaviors may facilitate the way children understand the causal mechanisms of gears, and the way that they interact with gears later when on their own. Children may develop new understanding of events in the world when their parents use language to support or interpret their actions, and when that language occurs at meaningful times during children's exploration.

More generally, sociocultural theory makes conceptually deeper claims than just that thinking occurs in context. For example, sociocultural theorists make assumptions about the person being transformed in social contexts that involve meaningful everyday activity, yet also argue that this is a dynamic process and that activities and social contexts themselves are transformed through people's actions. Packer and Goicoechea (2010) argue that "any social context—a classroom, for example—is itself the product of human language and social practice, not fixed but dynamic, changing over time" (p. 232). People's actions vary across activity settings, and different people make different meaning out of a given social context. Some theorists point out that experimental tasks are a type of activity setting as well, but one that often goes unexamined within the constructivist approach (Lave, 1988). Taking museums as an authentic activity setting, we are observing families' everyday behavior. We cannot be sure that these behaviors will generalize to all other settings, and we must acknowledge that not all families visit children's museums as a part of their everyday activity, but these acknowledgments are part and parcel of the sociocultural approach.

Observing families' interactions in authentic environments like museums, however, may serve as an example of a way of linking sociocultural and constructivist approaches. Further studies of meaningful talk and activity in other settings are warranted if we are to make progress toward a consolidated theory that considers both children's developing minds and children as participants in complex everyday activities and settings.

Sociocultural approaches also raise questions about variability in children's experience related to their cultural community and other aspects of their social context. Demographic variables figured differently in the different models that we constructed in Chapter VI. Specifically, in the Reactive model (the model in which causal language occurred after children completed systematic exploration), there were significant effects of parents' science background and general level of schooling. Individual differences among families based on these experiential factors might relate to how parents react to children's exploration, but that dynamic does not seem to predict whether children will engage in systematic exploration. General schooling level and science background seem to represent experiences that encourage parents to use a higher proportion of causal language, especially when commenting after children have systematically explored the gears. However, in the most predictive Lag model, in which parents used causal language prior to children systematically testing what they have built, there was no effect of parents' level of schooling or science background, and this was the model that seemed to provide a social context that may better support children's causal thinking. The relation between systematic exploration and causal thinking is a constructivist idea. In contrast, the finding that systematic exploration is more likely to appear in certain social contexts and not others, requires integrating constructivist thinking with sociocultural accounts.

This discussion suggests that there are other ways we might want to approach analyzing these data. Our GLMM analyses suggest that there are times when particular kinds of talk, in relation to the occurrence of particular behaviors, produce more of the exploratory actions on the part of children that might influence their causal thinking. Ideally, we could expand this approach to consider parents' actions as a way of trying to capture the kinds of teachable moments in an interaction that would support children's causal thinking or their problem solving more generally. We could also expand our investigation to other kinds of contingent behavior (such as eye contact or nonverbal facial expressions between social partners), whether parents and children were building gear machines together or separately, and how different kinds of causal language could prompt systematic exploration or other sequences of children's action that might relate to causal thinking. We could also try to describe best practices for museums that might encourage such interactions and the creation of such moments in authentic experiences between parents and children, however, this would first require more extensive research with a greater diversity of families. These are all jumping-off points for future investigations.

Implications for Research in Cognitive Development—Our findings provide important new understanding of the context of children's developing understanding of causal relations. We also discuss the methodological benefits of collaborative multisite studies.

Understanding Children's Causal Thinking and Persistence: Children's causal thinking is different from just their exploring or their explaining. One could argue that children's systematic exploration is nothing more than a kind of causal thinking, and thus one of the main findings of the SEM analysis—that their behavior predicts causal thinking measures—is trivial. However, systematic exploration in the context of families' play at the exhibit seems to be based not only on children's internal causal reasoning capacities, but also on the interaction between parent and child. Systematic exploration was not related to parents' language overall, but at certain key times during the exploration. Further, it was related to parent–child interaction styles, such that parents who set more goals might have limited the amount of systematicity that was inherent in children's exploration. In this way, parents' causal language might help bootstrap children's causal thinking through the support of children's exploration, while other environmental factors might support the type of environment parents provide for, or encounter with, their children as part of their everyday learning.

In contrast, resolute behavior—internal persistence on the part of the children during their exploration—might be based more on children's own internal motivation. These behaviors were not significantly correlated with parent–child interaction style or with parental language, but rather were more dependent on whether children generated certain kinds of language at certain times. That said, resolute behavior measures only one kind of persistence. These behaviors might reflect children's intrinsic motivation to solve local problems related to their motoric actions, and may not measure engagement with the exhibit. Medina and Sobel (in press) showed that jointly-directed interactions (compared to parent- or child-directed ones) resulted in children being more engaged with a novel learning environment (measured by the time children spent playing with an open-ended causal system, presented to them at a children's museum). Others have considered how other kinds of social interaction—in the form of praise or essentialized language—can relate to children's engagement with playful interactions (e.g., Gunderson et al., 2013; Rhodes, Leslie, Yee, & Saunders, 2019). A critical question that is still un-answered from the present investigation is how children's motivation and persistence relate to the model of causal thinking that we have suggested emerges from their interaction with the world.

Advantages of Collaborative Multisite Research Strategy: The data set we gathered in this research combines data collection efforts from three museums, each with its own idiosyncrasies. The advantage of this strategy is that we were able to consider the data as an overall sample (when patterns overlapped across sites), but we could also consider each site on its own and identify patterns where demographics and exhibit design may have revealed distinctive patterns. Had we conducted the study at any one of our three museum sites, we may have ended with quite different conclusions. Considering the patterns that are overlapping and those that are distinctive helped us to understand more about both the importance of variation in children's experiences, and the possibility of overarching patterns across communities and museums.

Our multisite strategy allowed us to also ask questions that we would be unable to ask if we were only working at one site. Resolute behaviors—children's troubleshooting when they encountered problems interacting with the exhibit—were different across the sites. The gear apparatus of Providence Children's Museum afforded us the opportunity to examine children's behavior when gear mechanisms were more challenging (as indicated by the overall greater proportion of attempts to connect or spin at this site). This resulted in our being able to document dynamics between children's troubleshooting exploratory behaviors and their relation to the language that children themselves generate.

Children's resolution of the problems they had interacting with the exhibit related to the language they generated, but only if they talked about their actions or the exhibit while they were experiencing the trouble. One might think about children's generation of language about their actions or the exhibit as functioning like potential explanations for their problems. Children might verbalize the problem they are having by describing their actions or some aspect of the exhibit. Verbalization helps children to develop cognitive skills related to self-regulated learning (e.g., Schunk, 1989). Verbalization also focuses children's attention on the problem, which might facilitate their ability to complete the task. Finally, it could be that all children are doing is articulating their experience to their parent, which might help them resolve the problem. Explaining behaviors to one's parents does facilitate problem solving (e.g., Rittle-Johnson et al., 2008).

Similarly, working across museum sites allowed us to compare free play at exhibits that had specific goals versus exhibits that did not. In particular, the exhibit at Children's Discovery Museum of San Jose had three gears that children could not reach or manipulate, but which children could connect to in order to make objects spin. For example, one gear had a ballerina on it, and children and parents could have the goal of making the ballerina spin by connecting other gears to it. In contrast, the Providence Children's Museum and Thinkery exhibits did not have such embedded goals, and were more open-ended in their structure. In this way, we examined the difference between systematic exploratory actions that were connected to this goal versus ones that were not. This analysis found that the dynamics of goal-directed connections versus open-ended connections were similar. Trying to connect to a goal did not affect the frequency of systematic exploration, but causal language still played a role in this model as it did in the main analysis. This suggests that working across sites allows for more robust conclusions.

Despite some of the differences in individual behaviors across the sites, it is also important to focus on some of the similarities among the sites. One such similarity is the general relations among children's exploration, the type of language they hear and generate, and their general parent–child interaction style. As mentioned above, an important facet of our analysis in Chapter VI is that we found few site differences in the dynamics among these behaviors. This suggests that the major findings of our investigation are not based on idiosyncrasies at one of the three sites, and might generalize widely.

More generally, an advantage of our multisite approach was the attempt to collect a more robust demographic sample. Although we suspect that the diversity of our sample was greater than it would have been at any individual museum or lab site because we tested in multiple sites across the United States, there are still concerns that collecting data from a museum may not provide a sample as diverse as the general population of the local geographic area. We made numerous efforts to collect data on free admission days or special cultural event days, and at various times of day both during the school year and the summer. Moreover, at all three sites, our research team included numerous students from communities that are underrepresented in science, many of whom spoke to parents in their native language. Even so, the diversity of our sample was not as high as we would have liked, particularly when we looked at household income and parents' schooling level, but also at racial and ethnic identity. This problem, however, is not unique to this project. Despite the valiant efforts of many children's museums, including notably our partner museums, it is still true that museums are not everyday settings for all families (Dawson, 2014; Feinstein, 2017; Garibay & Teasdale, 2019).

Given the demographics of our sample, we must use caution in considering how to interpret our findings. For example, we were not able to test complex models that include self-reported ethnicity. Except for the one analysis in Chapter V, showing that parent–child interaction style varied by ethnicity group, our sample sizes were too small and too heterogeneous to make strong claims about ethnicity differences. One of the limitations of this research is that we were unable to include ethnicity in our statistical models, even when there is a fair amount of diversity at a given site. Increasing inclusivity in developmental research by representing children's diverse experiences as they relate to ethnicity, race, and other cultural constructs, without inadvertently essentializing groups and contributing to deficit interpretations of differences remains an ongoing challenge for the field (see Callanan & Waxman, 2013; Gutiérrez & Rogoff, 2003; Medin et al., 2010).

The proclivity to essentialize groups illustrates why it is misleading to conceptualize ethnicity or culture as independent variables. Treating ethnicity or culture as independent variables encourages a view that these factors can be added or subtracted, controlled, or manipulated (Rogoff, 2003). Instead, we argue that developmental change is deeply embedded in cultural practices and in children's social experiences. Constraining our theories to a limited sample of children from WEIRD communities is far from sufficient (Henrich et al., 2010; Nielsen et al., 2017). Rowley and Camacho (2015) explain the important reasons that our field needs to increase diversity of participants in our research, as well as the challenges that make this progress difficult. As a field, it is critical to move toward better models of development that take culture variability as a given and consider diversity without assuming deficits or homogeneity.

Implications for Linking Research and Practice—Working with museum professionals has highlighted the overlapping interests of practitioners and researchers. We consider two ways that our findings can contribute not only to basic research, but also to strategies for supporting children's learning through play and parent–child interaction.

Best Practices in Play and Learning: Understanding cognitive development requires studying children learning from social interactions. In Chapter I, we highlighted one distinction that is critical to our study: the one between direct instruction and guided play. This distinction is usually discussed in terms of learning outcomes—that is, what is the "best" way for children to learn? Do children learn better from being given explicit instruction or from being guided through play?

There are various ironies about this dialogue. One is that children themselves overestimate the importance of their own actions and under-estimate the importance of instruction. Sobel and Letourneau (2018) found that the 3–4-year-olds they tested mostly thought that anything can be learned from exploration, while older 4- and 5-year-olds in their sample recognized the importance of instruction in learning certain kinds of information. Another irony is that although play is thought to be a fundamental avenue for many kinds of learning in early childhood, most research on children's understanding of play examines playing and learning as mutually exclusive, and more critically, the experiments are set up by adult researchers to reinforce that difference (e.g., Howard, Jenvey, & Hill, 2006; Karrby, 1990; Keating, Fabian, Jordan, Mavers, & Roberts, 2000; King & Howard, 2014; Robson, 1993; Rothlein & Brett, 1987). For example, Howard et al. (2006) asked children to categorize actions in photographs as either play or learning, implying that these two actions are mutually exclusive to one another.

We seek to reconceptualize the dialogue between direct instruction and guided play not as asking about the best way for children to learn, but rather as asking about the practices that support children’s learning. For example, it is tempting to think of parents in our parent-directed dyads as being too instructive or restrictive in their interaction, or to think about parents in child-directed dyads as too hands-off or uninvolved. But as we pointed out in the introduction, there are some learning environments in which circumstances might call for direct instruction about a particular topic or rule (Medina & Sobel, in press). Similarly, in naturalistic studies of whether parents notice their children learning, even parents who seemed the most hands-off could articulate observations of children’s behavior that they believed indicated learning (Letourneau, Meisner, Neuwirth, & Sobel, 2017).

There is no single best way for children to learn, broadly speaking, but rather patterns of exploration and explanation that create space for learning to occur, and cultural norms within families that provide children with opportunities to explain and explore further. Previous research on cultural variation in what counts as play and learning indicates that there are many paths toward learning (Gaskins, 2008a, 2008b; Parmar, Harkness, & Super, 2004). That said, there are also moments that are critical for learning to occur, and that can be identified, fostered, and elaborated upon in real-world interactions. The implications of this study for museum practice and early childhood education lie in revealing when and how caregivers’ talk and actions made a difference for causal learning. Studies such as these can provide insight into how museum spaces might support families’ interactions in specific ways—for example, designing the environment to create space for caregivers to explore alongside their children, or creating experiences with sufficient challenge to allow for some shared troubleshooting.

As a side note, in the prior paragraph, we used the word “caregiver” instead of the word “parent,” the term we have mostly been using throughout the monograph. This choice was intentional. Our Institutional Research Board protocols allowed us to include children as participants only if they had the signed permission of a parent or legal guardian. We thus thought it best to limit ourselves to that label when describing our results and their implications. We do think, however, that our work has implications for any caregiver interacting with children through play and exploration, particularly when considering museum practice. Do the dynamics between children’s exploration and language by the parent extend to dynamics created with any other adult or with a peer? Do the dynamics with nonparent caregivers or with peers have the same implications for children’s developing causal thinking? It is certainly possible. But there are also types of knowledge children learn more fully and most lastingly from parents or other adults, based on familiarity or other relationships children might have with these individuals, as well as types of knowledge children learn more from peers (e.g., Corriveau & Harris, 2009; Corriveau et al., 2009; VanderBorght & Jaswal, 2009). How children trust others and integrate that trust into the way they dynamically learn from their interactions is a subject for future investigation.

In addition, museum practitioners model ways of supporting learning in these environments, and their everyday practices involve noticing how family interactions are taking place, and deciding when and how to offer supports, suggestions, or additional challenges to children and their caregivers. Museum staff often think more broadly about the diverse types of caregivers who visit their spaces, with the goal of planning for a variety of ways of supporting children's learning. Researchers have often focused on the diversity of caregivers as well. For example, Sanford, Knutson, and Crowley (2007) interviewed grandparents visiting a museum with their grandchildren. Grandparents tended to articulate the importance of such visits for social interaction, potentially in ways that parents might not. Knowing more about how learning unfolds over time in the context of various family interactions provides practitioners with a lens for noticing patterns in visitor behavior, and additional evidence to guide their interactions with families. Finally, practitioners in informal learning environments have a role in building caregivers' and children's awareness about how they learn through their exploration, explanation, and social interactions. As many children's museums seek to articulate the value of learning through play and open-ended exploration, practitioners can use studies such as these to highlight the many behaviors that lead to learning in their spaces, and the many pathways that learning can take from moment to moment.

Partnering With Museums: The research we have described in this monograph is a joint and ongoing collaboration between university researchers and museum educators and practitioners. Comprehensive reviews of variations in these kinds of partnerships exist elsewhere (e.g., Callanan, 2012; Sobel & Jipson, 2016), so we have not discussed them in detail. We do want to highlight one implication of our investigation, which echoes an idea described by Haden, Cohen, Uttal, and Marcus (2016): One can think about projects between museums and academic researchers as verbal agreements in which academics simply use museum resources to produce academic scholarship, or as more collaborative wherein the partners engage in dialogue that facilitates each other's goals.

We argue that the collaboration documented here is jointly constructed. For example, our initial coding scheme for exploration came from collaborative interaction between museum staff and university researchers. At many steps through the construction of this monograph, museum educators worked with university researchers to construct these measures. An important goal in constructing our coding systems was to be able to apply it to other exhibits, not just the gear exhibits under consideration. Indeed, we have extended the parent–child interaction style coding scheme to another investigation on causal learning (Medina & Sobel, in press) and we are currently extending the exploration and explanation coding schemes to other exhibits at these museums (e.g., a circuit exhibit in Providence Children's Museum, see Sobel, Letourneau, Legare, & Callanan, 2019). In the longest running partnership of our three sites, the partnership between Callanan's lab and Children's Discovery Museum of San Jose has profoundly changed the focus of their research over time (Callanan, Martin, & Luce, 2016).

We would encourage researchers to reach out to bridge new partnerships with museums and other informal learning environments. Likewise, we would encourage informal learning practitioners to explore collaborations with researchers. When these research-practice partnerships are at their best, they are not only about evaluation of exhibits or programs, but a mutual process of professional engagement wherein both museum staff and researchers gain better skills in understanding both learning of visitors and development of children.

Final Thought

Above, we said that there is no single best way for children to learn. There is also no single best way to play and there is no single best way for parents to interact with children during play to support learning. Learning occurs at the interface between internal cognitive processes and the social interactions that contextualize those experiences. The moment-to-moment interactions between parents and children makes learning possible. Our research reveals key moments in the dynamics of these interactions that support learning. Through translating this research to practice, museums and informal learning environments can foster and build upon these moments as families continue learning together.

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Robin Gose is the President and CEO of MOXI: The Wolf Museum of Exploration and Innovation in Santa Barbara, CA. She has been a STEM educator for over 20 years, and was previously Director of Education at Thinkery in Austin, TX. At MOXI, she sets the strategic vision and oversees operation, finances, outreach, and programming to ensure alignment with the museum's mission "to ignite learning through interactive experiences in science and creativity."

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Janella Watson is an education, museum, and children's media consultant. She previously served as Associate Director of Providence Children's Museum, where she led the museum's communications, exhibits, and research departments, and spearheaded the organization's rich, community-rooted partnerships and initiatives. Janella is a founding member of the Association of Science and Technology Centers (ASTC) Early Childhood Community of Practice, and has served as an early STEM advisor and content/curriculum developer for Nickelodeon's Preschool Division and DreamWorks Animation Television.

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FIGURE 1. —.
Gear exhibits at (from top to bottom): Providence Children's Museum (RI), Children's Discovery Museum of San Jose (CA), and Thinkery in Austin (TX).

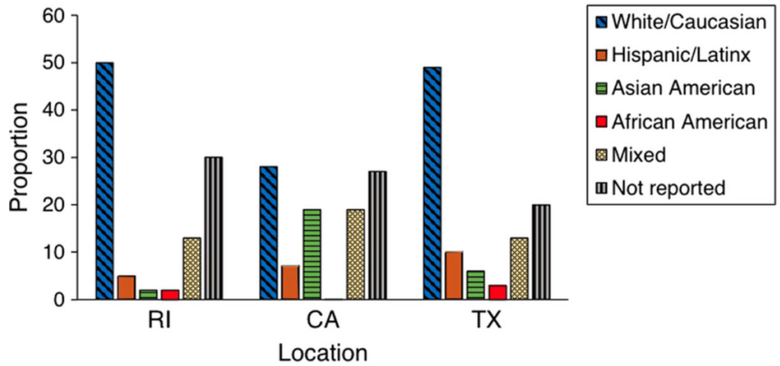

FIGURE 2. —.
Proportion of parents' self-reported ethnicity by site.

FIGURE 3. —.
Gear machine used throughout the follow-up tasks.

FIGURE 4. —.
Stimuli used in the color memory task. The researcher removed the pink gear (shown at bottom) and asked children which of the five gears (shown at the top) they remembered seeing in its location.

FIGURE 5. —.

Stimuli used in the mechanism task. The pink gear (shown at the bottom) was removed. Children were asked which of the five pieces at the top could be placed in its location to make the gear machine work.

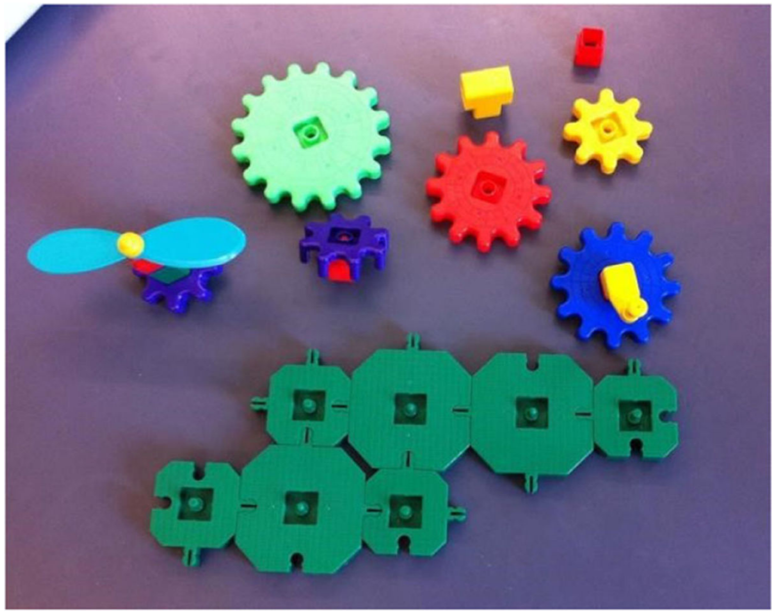

FIGURE 6. —.

Stimuli presented to children in the reconstruction task. Children were instructed to put the machine back together the way it was before (as shown in Figure 3) and make it work?

FIGURE 7. —.
Stimuli used in the generalization task. Children were shown these stimuli and asked whether they can build a new machine with these pieces any way they want.

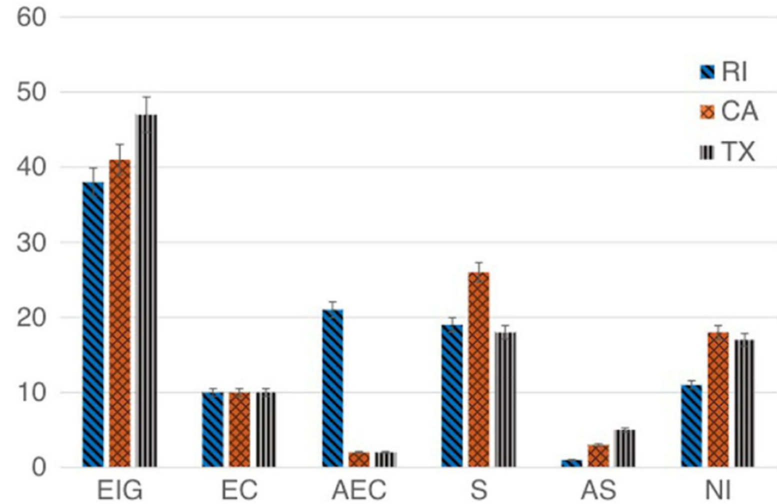

FIGURE 8. —.

Proportion of 5-s exploration sequences by site. *Note*. AEC = attempting to explore connections; AS = attempting to explore gear machines (attempting to spin); EC = exploring connections; EIG = exploring individual gears; NI = not interacting with the exhibit; S = exploring gear machines (spinning).

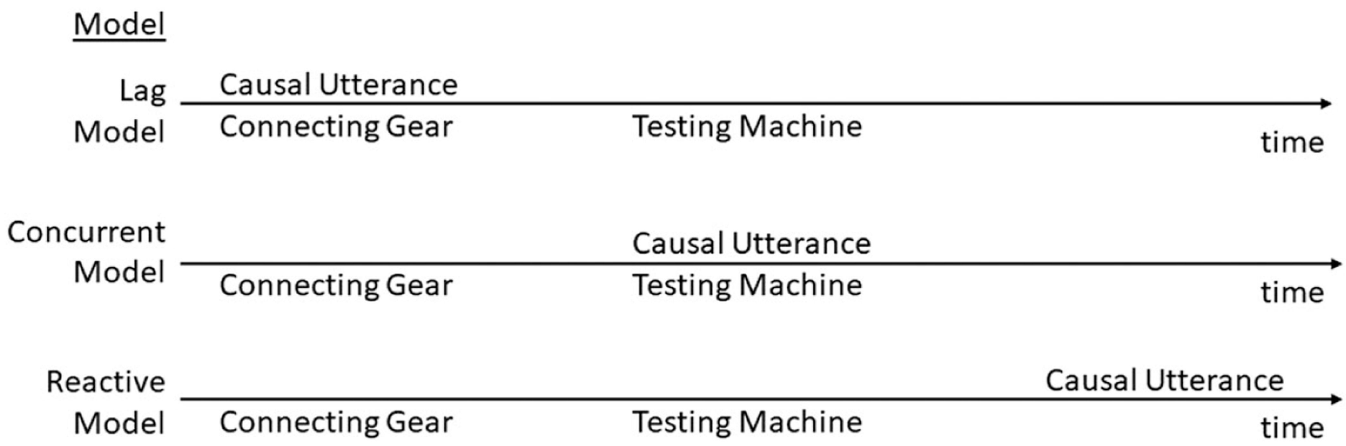

FIGURE 9. —.

Representations of the event sequences between Lag, Concurrent, and Reactive Models used in Analysis of Systematic Exploration.

FIGURE 10. —.
Visual reference for an alphanumeric coding scheme for the generalization task.

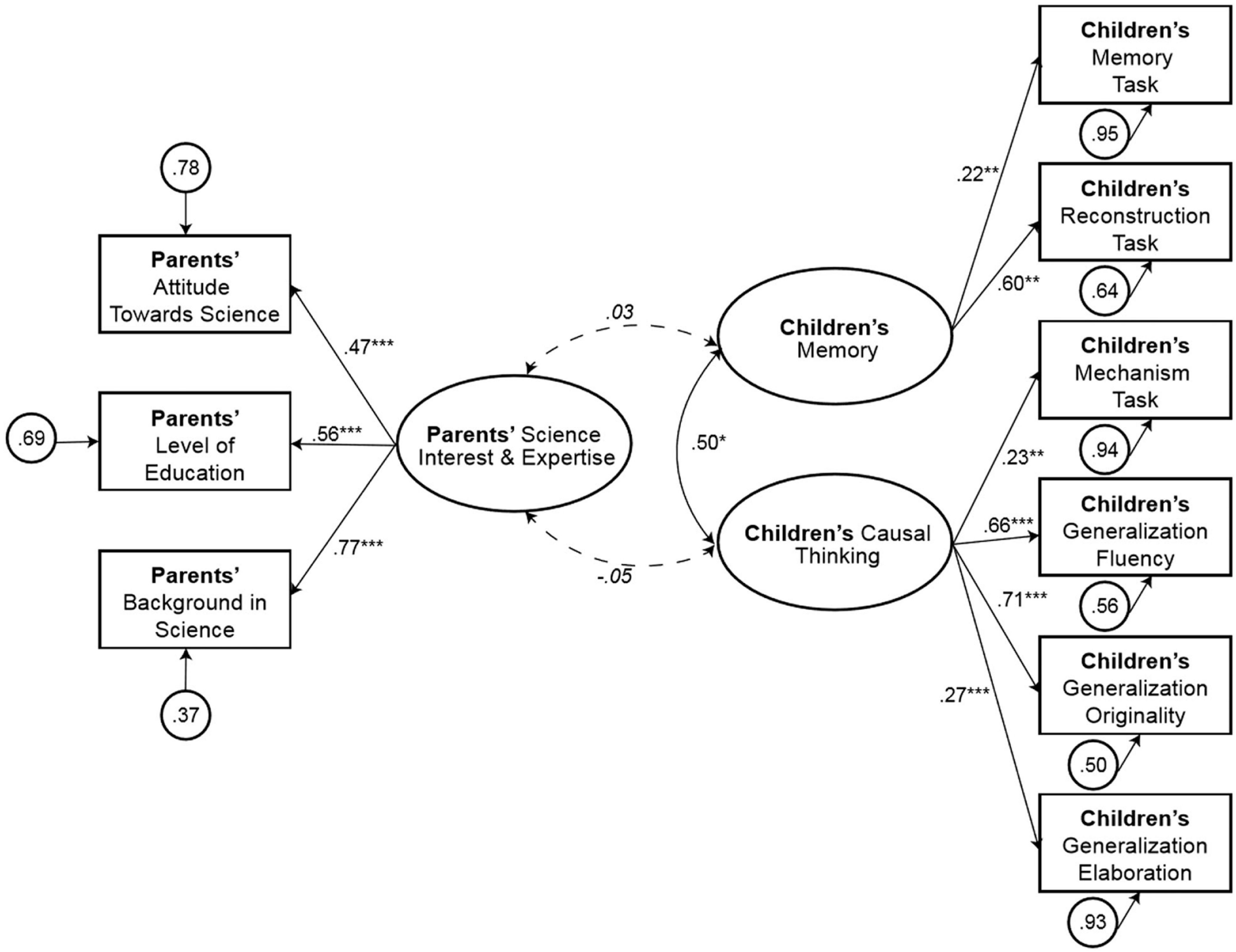

FIGURE 11. —.

Results of confirmatory factor analysis relating three latent factors to observed variables. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

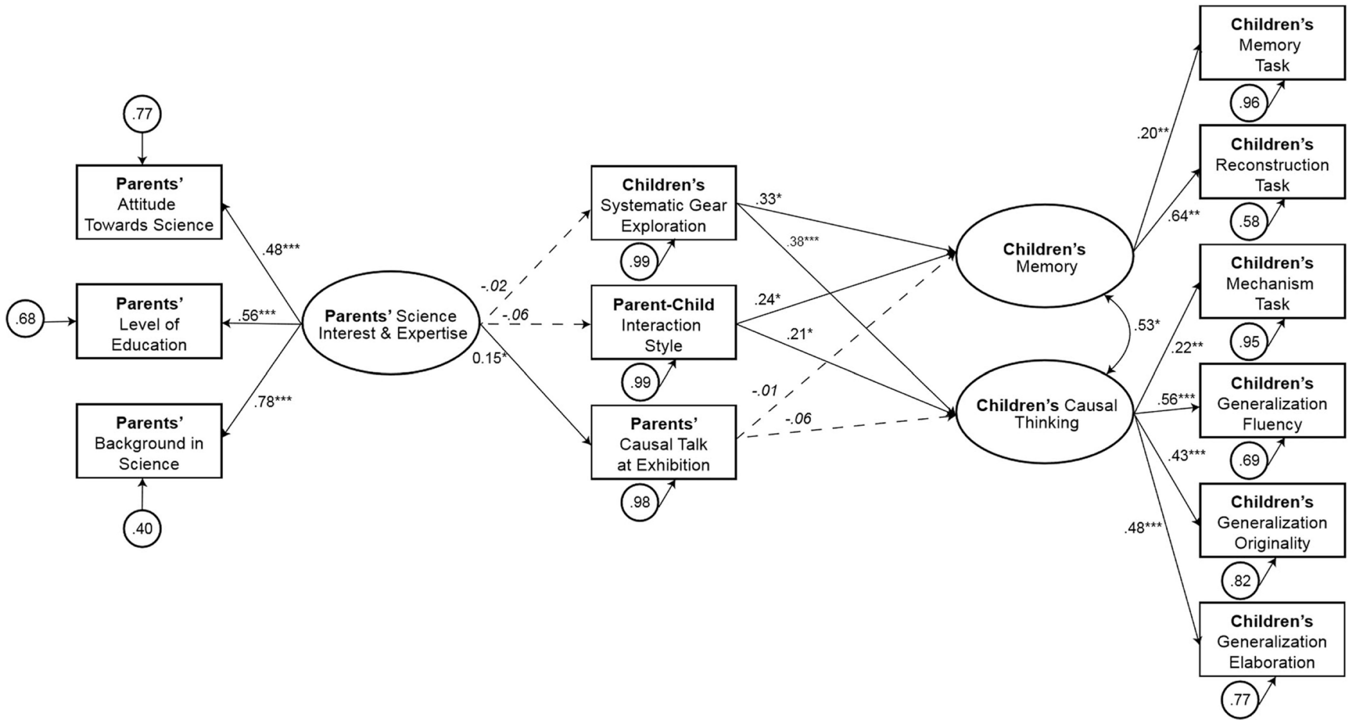

FIGURE 12. —.

Structural equation model detailing relations among latent factors and observed variables. *$p < .05$, **$p < .01$, ***$p < .001$.

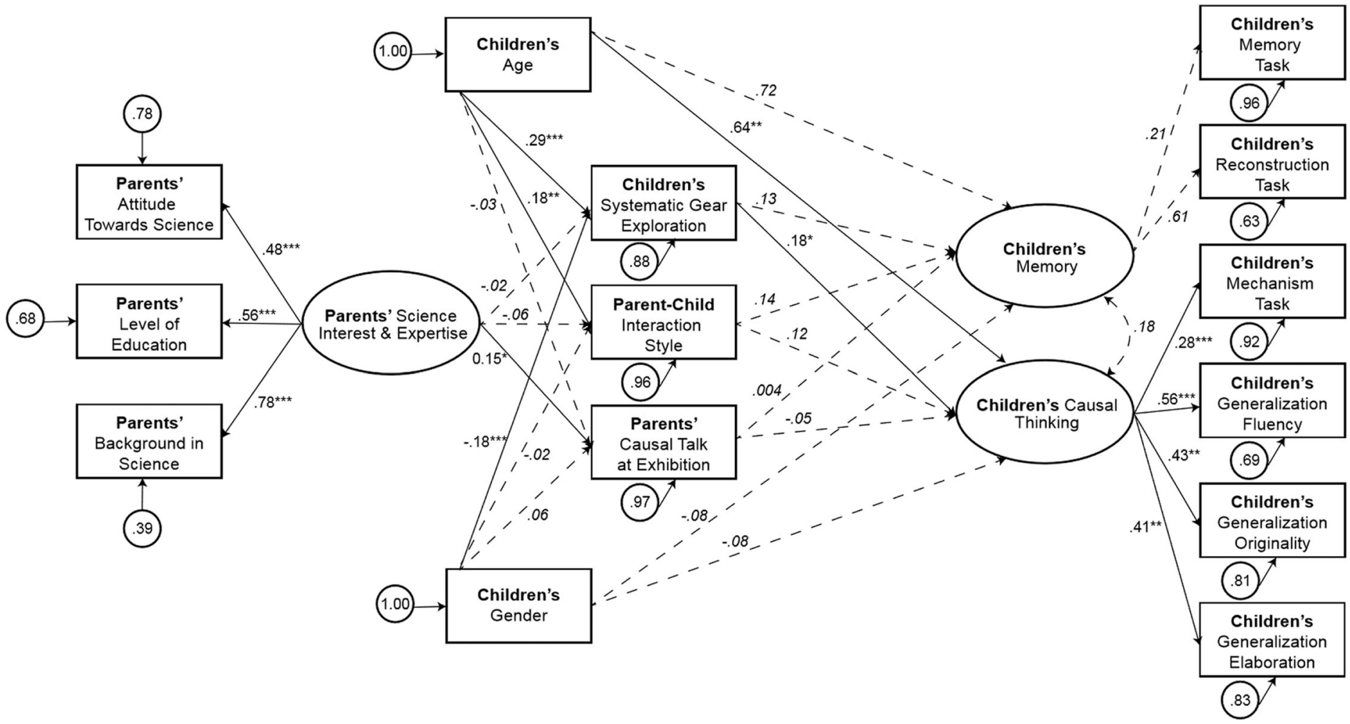

FIGURE 13. —.

Structural equation model detailing relations among latent factors and observed variables, including children's age and gender. *$p < .05$, **$p < .01$, ***$p < .001$.

TABLE 1

Distributions of Family income, Parental Education, Parental Science Background, and Museum Experience by Site

	RI		CA		TX		Pooled	
	n	%	*n*	%	*n*	%	*N*	%
Income								
<30 K	7	6	3	3	5	5	15	5
31–50 K	15	13	5	5	12	12	32	10
51–70 K	15	13	10	9	10	10	35	11
71–90 K	17	15	8	7	16	15	41	13
91–120 K	19	17	13	12	22	21	54	17
>120 K	28	25	57	52	26	25	111	34
Not reported	11	10	13	12	13	13	37	11
Education								
Some high school	1	1	1	1	2	2	4	1
High school graduate	8	7	2	2	4	4	14	4
Some university	14	13	18	17	13	13	45	14
Associate degree	10	9	3	3	8	8	21	7
Bachelor’s degree	44	39	34	31	36	35	114	35
Master’s degree	23	21	34	31	23	22	80	24
Doctorate or professional degree	5	4	12	11	11	11	28	9
Not reported	9	8	5	5	7	7	21	6
Science education								
No STEM education	56	50	41	38	69	66	166	51
Bachelor’s degree in STEM	42	38	35	32	25	24	102	31
Advanced degree in STEM	14	13	33	30	10	10	57	18
Museum visitation First time	29	26	37	34	41	39	107	33
1–2 times	41	37	35	32	18	17	94	29
3–5 times	17	15	21	19	17	16	55	17
6-9 times	15	13	8	7	8	8	31	10
10 or more times	9	8	6	6	16	15	31	10
Not reported	1	1	2	2	4	4	7	2

Note. Due to rounding, percentages may not add to 100%.

TABLE 2

Zero-order Correlations Among Parent Demographic Variables (Pooled across sites)

	Household Income		Science Background		Attitudes toward Science		Gender	
	r_s	p	r_s	p	r_s	p	r_s	p
Education	.50	<.001	.33	<.001	.22	<.001	−.17	.002
Household income	–	–	.21	<.001	.11	<.001	−.16	.003
Science background	–	–	–	–	.38	<.001	−.26	<.001
Attitudes toward science	–	–	–	–	–	–	−.16	.004

Note. Parent gender was scored 0 = *male*, 1 = *female*.

TABLE 3

CODING RUBRIC FOR CHILDREN'S EXPLORATORY BEHAVIOR

Code	Description	Behaviors Included
Exploring individual gears	Coded when child picked up and manipulated an individual piece or element of the exhibit, but did not engage with more than one piece.[a]	• Holding piece • Placing piece on the exhibit without contacting other gears • Fiddling with piece position • Spinning a single gear (unconnected to another gear) • Putting a piece away
Exploring connections	Coded when child connected or disconnected individual gears together in ways that allowed child to engage in, or to stop engaging in, causal function.	• Connecting teeth of two or more gears without spinning the gears • Adding a gear to an already constructed set of connected gears (referred to as a *gear machine*) • Disconnecting gears to reorganize a gear machine (i.e., disconnecting a gear and connecting it to a different gear on a different part of the exhibit) • Connecting two gears in the air or—at CA or TX—without magnetic bases so they would not stick to the table
Attempting to explore connections	Coded when child unsuccessfully tried to connect two gears. Code applied only if child was judged to be attempting to connect gears (i.e., gears must have been touching with the possibility that their teeth could connect).[b]	• Repeated attempts to connect gear to another gear • Repeated attempts to place gear in pegboard (in RI) in a position that would allow it to connect with another gear
Exploring gear machines	Coded when child manipulated a gear machine by spinning the gears, hence putting the causal process into action. The machine being spun could have been one constructed by the child or one that had been provided as part of the exhibit. To receive this code, children must also have been looking at the result of their action.	• Turning one gear on a connected machine, thereby causing at least one other gear to spin
Attempting to explore gear machines	Coded when child attempted to spin gears that move other gears in a machine, but the gears did not spin.	• Attempting to spin a gear machine but failing to get it to spin perhaps because gears jammed (usually in RI) or because they drifted apart while spinning (in CA and TX).
Not interacting with exhibit	Coded cases when child was not interacting with the exhibit materials, but was facing the exhibit.	• Observing the parent without exploring any of the materials • Leaning on the exhibit but not manipulating gears • Passively touching a gear on the exhibit without manipulating it while looking off at something else.
Not codable	Coded when *none* of the child's actions were visible during the full 5-s interval. (If actions were visible during part of the interval, codes were assigned based on behaviors observed during that time.)	• Child was positioned so that their hands were not visible • Child was not facing the exhibit or engaging with the gears • Child was off camera

[a]In CA and TX, this code was used when child attached a gear to a magnetic base because such an attachment was a necessary first step before it would be possible to connect one gear to another (see Chapter II).

[b]If a child initially "attempted" but ultimately succeeded in connecting gears during a 5-s interval, the interval was coded as Exploring Connections (rather than as Attempting).

TABLE 4

Correlations Among Children's Age, Gender, and Proportions of Each Exploration Category by Site

Child Demographic	Exploration Category	Site		
		RI	CA	TX
Age	Exploring individual gears	$r_s(110) = -.24$	$r_s(105) = .01$	$r_s(102) = -.24$
		$p = .01$	$p = .94$	$p = .02$
	Exploring connections	$r_s(110) = .22$	$r_s(105) = .47$	$r_s(102) = .41$
		$p = .02$	$p < .001$	$p < .001$
	Attempting to explore connections	$r_s(110) = .38$	$r_s(105) = .33$	$r_s(102) = .15$
		$p < .001$	$p = .001$	$p = .13$
	Exploring gear machines	$r_s(110) = -.02$	$r_s(105) = -.20$	$r_s(102) = .20$
		$p = .81$	$p = .04$	$p = .04$
	Attempting to explore gear machines	$r_s(110) = .34$	$r_s(105) = .05$	$r_s(102) = .21$
		$p < .001$	$p = .64$	$p = .03$
	Not interacting with exhibit	$r_s(110) = -.27$	$r_s(105) = -.36$	$r_s(102) = -.27$
		$p = .04$	$p < .001$	$p = .005$
Gender	Exploring individual gears	$r_s(110) = -.07$	$r_s(106) = -.12$	$r_s(102) = .12$
		$p = .50$	$p = .24$	$p = .23$
	Exploring connections	$r_s(110) = -.03$	$r_s(106) = -.21$	$r_s(102) = -.26$
		$p = .79$	$p = .03$	$p = .007$
	Attempting to explore connections	$r_s(110) = .09$	$r_s(106) = -.14$	$r_s(102) = -.26$
		$p = .33$	$p = .16$	$p = .008$
	Exploring gear machines	$r_s(110) = -.08$	$r_s(106) = .04$	$r_s(102) = -.09$
		$p = .40$	$p = .71$	$p = .36$
	Attempting to explore gear machines	$r_s(110) = .02$	$r_s(106) = -.03$	$r_s(102) = -.07$
		$p = .84$	$p = .79$	$p = .46$
	Not interacting with exhibit	$r_s(110) = .02$	$r_s(106) = .15$	$r_s(102) = .17$
		$p = .87$	$p = .12$	$p = .09$

Note. Data from one CA family were omitted because of incomplete age information; gender was coded 0 = *boy*, 1 = *girl*.

TABLE 5

Correlations Among Proportions of Particular Sequences of Exploration and Children's Age and Gender by Site

Child Demographic	Site	Systematic Exploration	Resolute Behavior
Age	RI	$r_s(110) = .28$	$r_s(110) = .37$
		$p = .003$	$p < .001$
	CA	$r_s(105) = .32$	$r_s(105) = .10$
		$p = .001$	$p = .33$
	TX	$r_s(102) = .37$	$r_s(102) = .20$
		$p < .001$	$p = .04$
	Combined	$r_s(321) = .31$	$r_s(321) = .24$
		$p < .001$	$p < .001$
Gender	RI	$r_s(110) = -.04$	$r_s(110) = -.03$
		$p = .71$	$p = .79$
	CA	$r_s(106) = -.22$	$r_s(106) = -.15$
		$p = .02$	$p = .13$
	TX	$r_s(102) = -.26$	$r_s(102) = -.27$
		$p = .008$	$p = .006$
	Combined	$r_s(322) = -.17$	$r_s(322) = -.12$
		$p = .002$	$p = .03$

Note. Gender was coded 0 = *boy*, 1 = *girl*.

TABLE 6

Coding Rubric for Parents' and Children's Talk

Category	Code	Description	Example
Causal language	Causal connection statement	Statements about how a specific action leads to a consequence. Must include mention of both the cause/action and the effect in the exhibit.	"When you turn this gear, it makes this gear spin."
	Causal connection question	Questions asking someone about the cause of a given effect, or the effect of one's action. These questions usually included "why" or "how."	"Why did this one start to turn?" "How did that happen?" "How can we make that one spin?"
	Making prediction statement	Statements suggesting that something will happen as a consequence of an action.	"I think this one will spin the other way."
	Making prediction question	Questions requesting a prediction about a causal relation. This code did not include what-if questions that only prompted an action.	"What do you think will happen if we move this closer?" "What happens if you turn it the other way?"
	Personal connection statement	Statements that relate the experience to a previous personal experience or a piece of information with personal relevance to the child or parent.	"This is like on your bicycle" "This is how our clock at home works."
	Personal connection question	Questions that request a connection to a personal experience or piece of information with personal relevance to the child or parent.	"What does this remind you of that we did last summer?" "What do the gears on your bike do?"
	Science principle statement	Statements that relate the experience to a larger scientific principle or knowledge about a general concept. This code also applied to utterances involving analogy to a more general principle.	"Gears make things turn." "This is like how clocks work."
	Science principle question	Questions that ask for a broader scientific principle or knowledge about a general concept.	"How do gears make things work?"
	Labeling or describing the exhibit, causal mechanism statement	Statements that name parts of the exhibit or talk about aspects of the exhibit that are relevant to the causal mechanism (i.e., how the gears fit together or cause other gears to spin). This code also applied to utterances that mention causally relevant properties, such as gears' size or shape, the teeth on the gears or how they interlock, the direction or speed that the gears spin, and whether a gear will "fit" in a given spot. At individual sites, this code was also assigned based on particular features of the exhibit.	"It's stuck." "The gears have ridges." "These are the teeth on the gear." "That gear is going backwards." "Now they're connected." "You can move them around." "You can spin them."
	Labeling or describing the exhibit, causal mechanism question	Questions that ask for a label or description that is relevant to the causal mechanism.	"Does it connect?" "What direction is that one spinning?" "Where will that one fit?"
Noncausal talk about the exhibit or about actions	Labeling or describing the exhibit, irrelevant to causal mechanism statement	Statements that name or talk about aspects of the exhibit with no obvious connection to the causal mechanism (any other aspect of the exhibit besides how the gears fit together or make other gears spin). Includes talk about the color or decorative aspects of the gears, the number of gears on the table/board, or other parts of the exhibit. This code was also used for labeling gears without any further information.	"The doll is pretty." "It's purple." "That's a clock." "There are three." "That's called a gear."
	Labeling or describing the exhibit, irrelevant to causal mechanism question	Questions that ask for a label or a description that is irrelevant to a causal mechanism.	"How many gears are there?" "What color are they?" "Is it a gear?
	Directing another's action	Imperative statements telling another person what to do. This generally includes statements about what someone needs to do, should do, or has to do. No causal relation is mentioned in these statements.	"Turn it the other way." "Move that one over." "Now spin it." "Try it." "You need to move it."
	Suggesting/ scaffolding actions	Prompts or suggestions that imply performing an action, not as an imperative, but in a subtler way. This can be done as stating a possibility or as a rhetorical question. This category includes	"Maybe there's somewhere else you can put that one."

Category	Code	Description	Example
		asking or requesting that someone perform an action but with no causal relation mentioned.	"What if we use the big gears?" "You can move them if you want." "Can you move that gear?" "Want to try it?"
	Narrating own or others' action	Statements about what the speaker or another person did, is doing, or will do, without directing another person to perform an action, or mentioning a causal relation. Also questions where speaker is narrating action or events (rather than requesting that someone perform an action).	"I'm going to put this one over there." "I'll do it." "You're turning it!" "Did you get it to fit?
	Open-ended question	Questions that do not include a specific suggestion. Includes asking someone about what they are doing/ plan to do without constraining the answer, specifically when the question did not suggest a particular action. This code was also used to ask about someone else's preferences or opinions and ideas.	"What do you want to do next?" "Which one are you going to try?" "Do you want me to help?" "Want to keep playing?" "What do you think?"
Other kinds of noncausal talk	Guiding attention	Statements that suggest that the other person focus on some part of the exhibit, without describing it.	"Look over there and see what's happening." "Watch this, Mom!"
	Guiding attention question	Questions that ask for the attention of another person.	"Can you see how it looks from up above?"
	Emotion	Expressions of emotion, such as awe, frustration, pride, or humor.	"Wow!" "Cool!" "Uh oh!"
	Emotion question	Questions that ask about another's emotion.	"Did that surprise you?"
	Praise	Statements that praise the action of the other person.	"Good job!" "You're so smart."
	Praise question	Questions that ask for praise or evaluation.	"Did I do a good job?"
	Other utterance, on task	Any statements or questions that do not fit into categories above or do not have enough information to categorize but are on-task (focused on the exhibit).	"Yes." "Hmm." "Okay." "Maybe." "You know what?"
	Other utterance, off task	Any statements or questions that do not fit into categories above and are generally off task. Includes talk about being finished playing or ready to move on.	"I'm hungry." "Can we leave now?" "Are you all finished?" "I'm all done with gears."

TABLE 7

PROPORTION OF PARENTAL UTTERANCES ASSIGNED TO EACH CODE BY SITE

	Site								
	RI N = 112		CA N = 109		TX N = 104		Total N = 325		Differences Among Sites
Code	**Prop**	***SD***	**Prop**	***SD***	**Prop**	***SD***	**Prop**	***SD***	**Kruskal-Wallis $\chi^2(2)$**
Causal connections	.024	.057	.019	.011	.023	.036	.022	.042	1.26 $p = .53$
Causal connection questions	.013	.025	.023	.016	.013	.026	.016	.027	21.56 $p < .001$
Making predictions	.002	.008	.003	.003	.005	.011	.003	.009	3.96 $p = .14$
Making prediction questions	.006	.017	.006	.006	.010	.017	.007	.016	7.39 $p = .03$
Personal connections	.008	.057	.006	.008	.010	.036	.008	.040	17.51 $p < .001$
Personal connection questions	.003	.014	.001	.003	.004	.013	.003	.012	11.51 $p = .003$
Scientific principle	.006	.029	.001	.003	.004	.014	.004	.019	6.93 $p = .03$
Scientific principle questions	<.001	.002	.001	.002	.002	.008	.001	.005	1.45 $p = .49$
Causally relevant labels or descriptions	.104	.094	.158	.044	.078	.064	.114	.085	58.74 $p < .001$
Causally relevant questions about labels or descriptions	.038	.054	.050	.024	.034	.040	.041	.046	15.10 $p = .001$
Total causal language	.205	.145	.266	.096	.180	.114	.217	.125	37.40 $p < .001$
Causally irrelevant labels or descriptions	.015	.032	.077	.051	.061	.066	.051	.057	108.29 $p < .001$
Causally irrelevant questions about labels or descriptions	.014	.033	.033	.033	.040	.050	.029	.041	47.63 $p < .001$
Directive statements	.186	.154	.123	.102	.111	.111	.141	.129	19.54 $p < .001$
Scaffolding suggestions	.097	.102	.075	.055	.123	.094	.098	.088	18.86 p < .001
Narrative utterances	.101	.097	.128	.055	.129	.080	.119	.080	18.44 $p < .001$

	Site								Differences Among Sites
	RI *N* = 112		CA *N* = 109		TX *N* = 104		Total *N* = 325		
Code	Prop	*SD*	Prop	*SD*	Prop	*SD*	Prop	*SD*	Kruskal-Wallis $\chi^2(2)$
Open-ended questions	.027	.062	.013	.023	.043	.049	.027	.049	25.09 $p < .001$
Total exhibit/action talk	.440	.176	.448	.105	.503	.157	.463	.151	14.02 $p = .001$
Attention statements	.044	.056	.052	.046	.053	.052	.049	.052	7.42 $p = .02$
Attention questions	.009	.020	.009	.018	.003	.012	.007	.017	19.09 $p < .001$
Emotion statements	.046	.055	.052	.047	.044	.041	.048	.049	4.26 $p = .12$
Emotion questions	.003	.009	<.001	.001	<.001	.002	.001	.006	16.51 $p < .001$
Praise statements	.054	.083	.013	.020	.021	.034	.030	.057	20.69 $p < .001$
Praise questions	<.001	.001	<.001	.002	<.001	<.001	<.001	.001	0.43 $p = .81$
Other on-task utterances	.112	.109	.105	.068	.092	.070	.103	.085	2.32 $p = .31$
Other off-task utterances	.088	145	.054	.102	.096	.141	.079	.132	6.24 $p = .04$
Total other talk	.355	.176	.286	.119	.307	.168	.317	.159	13.10 $p = .001$

TABLE 8

Proportion of Children's Utterances Assigned to Each Code by Site

Code Category	Site: RI *N* = 112 Prop	RI *SD*	CA *N* = 109 Prop	CA *SD*	TX *N* = 104 Prop	TX *SD*	Total *N* = 325 Prop	Total *SD*	Differences Among Sites Kruskal-Wallis $\chi^2(2)$
Causal connections	.009	.024	.009	.037	.012	.044	.010	.036	0.43 $p = .81$
Causal connection questions	.007	.022	.019	.053	.003	.012	.010	.035	14.93 $p = .001$
Predictions	.003	.014	.003	.009	.005	.016	.003	.013	1.52 $p = .47$
Prediction questions	.001	.005	<.001	.003	<.001	.003	<.001	.004	0.38 $p = .83$
Personal Connections	.001	.006	.004	.017	.007	.028	.004	.019	5.86 $p = .06$
Personal connection questions	<.001	.004	<.001	.002	<.001	.001	<.001	.002	0.48 $p = .79$
Scientific principle	.002	.018	<.001	<.001	.004	.021	.002	.016	5.65 $p = .06$
Scientific principle questions	<.001	.003	<.001	.003	.001	.011	.001	.006	0.39 $p = .83$
Causally relevant labels or descriptions	.131	.166	.157	.118	.081	.101	.123	.135	24.99 $p < .001$
Causally relevant questions about labels or descriptions	.007	.018	.014	.028	.010	.041	.010	.030	8.40 $p = .02$
Total causal language	.151	.176	.201	.139	.121	.136	.158	.155	22.21 $p < .001$
Causally irrelevant labels or descriptions	.065	.171	.135	.123	.123	.168	.108	.158	44.31 $p < .001$
Causally irrelevant questions about labels or descriptions	.007	.031	.037	.083	.007	.017	.017	.054	40.28 $p < .001$
Directive statements	.067	.096	.026	.052	.045	.063	.046	.075	10.52 $p = .005$
Scaffolding suggestions	.021	.072	.013	.031	.016	.035	.017	.050	2.81 $p = .25$
Narrative utterances	.233	.221	.177	.148	.165	.153	.192	.179	4.95 $p = .08$
Open-ended questions	.006	.022	.005	.024	.021	.102	.011	.061	5.71 $p = .06$
Total exhibit/action talk	.375	.258	.384	.193	.373	.250	.377	.235	0.06 $p = .80$
Attention statements	.051	.088	.043	.112	.042	.067	.046	.091	0.45 $p = .80$
Attention questions	.006	.023	.002	.008	.001	.010	.003	.015	4.81 $p = .09$
Emotion statements	.041	.083	.076	.090	.056	.084	.058	.086	22.11 $p < .001$
Emotion questions	.001	.008	<.001	<.001	<.001	<.001	<.001	.004	6.01 $p = .05$
Praise statements	.002	.015	.001	.006	.001	.007	.001	.010	0.01 $p = .99$

Code Category	Site								Differences Among Sites Kruskal-Wallis $\chi^2(2)$
	RI N = 112		CA N = 109		TX N = 104		Total N = 325		
	Prop	*SD*	Prop	*SD*	Prop	*SD*	Prop	*SD*	
Praise questions	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001 p = 1.00
Other on-task utterances	.207	.190	.212	.151	.221	.197	.213	.180	0.93 p = .63
Other off-task utterances	.131	.195	.065	.102	.180	.250	.125	.197	10.44 p = .005
Total other talk	.411	.255	.388	.192	.496	.266	.431	.243	9.15 p = .01

TABLE 9

Zero-Order Correlations Among the Proportions of Children's Systematic Exploration and Resolute Behavior and The Proportions of Parents' and Children's Coded Language

	Parents' Causal Language	Parents' Exhibit/Action Talk	Parents' Other Talk	Children's Causal Language	Children's Exhibit/Action Talk	Children's Other Talk
Proportion of systematic exploration	$r_s(322) = .12$, $p = .03$	$r_s(322) = .07$, $p = .19$	$r_s(322) = -.09$, $p = .10$	$r_s(322) = .10$, $p = .08$	$r_s(322) = .07$, $p = .24$	$r_s(322) = .04$, $p = .48$
Proportion of resolute behavior	$r_s(322) = .06$, $p = .29$	$r_s(322) = .08$, $p = .15$	$r_s(322) = -.06$, $p = .28$	$r_s(322) = .02$, $p = .75$	$r_s(322) = .12$, $p = .03$	$r_s(322) = -.06$, $p = .26$

TABLE 10

CODING RUBRIC FOR PARENT–CHILD INTERACTION (PCI) STYLE

PCI Style	Description
Parent-directed	Parent leads interaction by • Setting goals for the child • Using imperative statements or giving step-by-step instructions in teacher-like tone • Placing or connecting gears in the exhibit or directly instructing child to do so in particular way • Solving problems or directing child on how to solve problems Child rarely makes decisions or voices goals
Child-directed	Child leads interaction by • Setting goals • Making decisions • Solving problems Parent guides child by • Asking questions or making suggestions • Offering help when needed • Observing child play and occasionally commenting, praising, or encouraging • Avoiding stepping in to solve problems Parent and child may act in parallel, both playing with the exhibit, but each interacts with different pieces and establishes own goals
Jointly-directed	Parent and child both lead by • Jointly setting goals • Contributing together to solutions when problems arise Parent encourages collaboration by • Making suggestions or giving hints • Avoiding direct instruction or imperative statements • Basing suggestions on child’s current or previous actions • Avoiding language implying they know more than child

TABLE 11

Demographic Information Across the Three Parent–Child Interaction (PCI) Styles by Site

Variable	Site	PCI Style						Rank Comparison Among
		Parent-Directed		Jointly-Directed		Child-Directed		Three Parent-Child Interaction Groups
Age (in months)	RI	52.47 (8.54) (N=23)		60.93 (13.57) (N= 43)		63.79 (13.99) (N= 46)		Kruskal-Wallis χ^2(2, N= 112) = 11.49, p = .003
	CA	56.56 (14.05) (N= 40)		60.42 (11.31) (N= 42)		63.52 (16.03) (N=26)		Kruskal-Wallis χ^2(2, N= 108) = 4.03, p = . 13
	TX	60.32 (16.21) (N=12)		58.84 (13.04) (N=72)		58.99 (13.02) (N=20)		Kruskal-Wallis χ^2(2, N= 104) = 0.03, p = .99
	Total	55.91 (12.90) (N=75)		59.84 (12.71) (N= 157)		62.67 (14.37) (N=92)		Kruskal-Wallis χ^2(2, N = 324) = 10.42, p = .005
Children's Gender (ns)		Girls	Boys	Girls	Boys	Girls	Boys	
	RI	11	12	21	22	21	25	X^2{2, N = 112) = 0.93, p = .95
	CA	22	19	23	19	13	13	X^2(2, N = 109) = 0.15, p = .93
	TX	5	7	37	35	10	10	χ^2(2, N = 104) = 0.39, p = .82
	Total	38	38	81	76	44	48	X^2(2, N = 325) = 0.33, p = .85
Caregiver's Gender (nS)		Mothers	Fathers	Mothers	Fathers	Mothers	Fathers	
	RI	18	4	36	7	37	9	X^2(2, N= 111) = 0.16, p = .92
	CA	18	23	28	14	12	13	X^2(2, N = 108) = 4.75, p = .09
	TX	7	5	48	23	12	8	X^2(2, N = 103) = 0.66, p = .72
	Total	43	32	112	44	61	30	X^2(2, N = 322) = 4.79, p = .09

Note. Three parents did not provide their gender on the forms. One parent did not report their child’s age in months.

TABLE 12

Numbers of Parent–Child Dyads in Each Interaction Style by Parent Ethnicity, Pooled Across Sites

	Parent-Directed	**Jointly-Directed**	**Child-Directed**
White/Caucasian	23 (30)	75 (48)	39 (42)
Hispanic/Latinx	7 (9)	11 (7)	5 (5)
Asian-American	15 (20)	8 (5)	6 (7)
African-American	0 (0)	3 (2)	2 (2)
Mixed	11 (15)	23 (15)	14 (15)
Not reported	20 (26)	37 (23)	26 (28)
Total number of dyads	76	157	92

Note. Numbers in parentheses show percentage of each ethnicity within a given parent–child interaction style.

TABLE 13

Significant Results (p-Values) of Generalized Linear Mixed Models to Analyze Systematic Exploration Between Parents and Children Based on the Lag, Concurrent, and Reactive Models

	Site RI			PCI Child Directed		Children's		Parents'						Model Fit	
												Type of Talk			
Model	CA	TX	Time	Parent Directed	Jointly Directed	Age	Gender	ATS	Level of Education	Science Experience	Household Income	Causal	No PT	AIC	BIC
Lag	.03	.50	.29	<.001	.60	<.001	.54	.13	.07	.35	.31	.002	.54	69,768	69,783
Concurrent	.57	.95	.91	.006	.55	<.001	.47	.09	.18	.51	.84	.48	.04	69,800	69,815
Reactive	.02	.04	.62	.02	.88	.01	.48	.84	.01	.005	.90	.14	.66	69,951	69,966

Note. AIC = Akaike information criterion; ATS = attitudes toward science (parental mean score); BIC = Bayesian information criterion; DV = systematic exploration; No PT = no parental talk during time interval; PCI = parent–child interaction style; Time = time interval during exploratory play.

TABLE 14

Significant Results (p-Values) for Lag, Concurrent, and Reactive Generalized Linear Mixed Models for Systematic Exploration in CA Data Set Only, Including Engagement With Goal

			PCI Child-Directed		Children's		Parents'				Model Fit	
									Type of Talk			
Model	**Time**	**Goal**	**Parent-Directed**	**Jointly-Directed**	**Age**	**Gender**	**ATS**	**Level of Education**	**Causal**	**No PT**	**AIC**	**BIC**
Lag	.55	.23	<.001	.81	.01	.54	.12	<.001	.03	.76	10,791	10,802
Concurrent	.14	.12	.009	.57	.008	.89	.16	<.001	.81	.78	9,835	9,846
Reactive	.51	.10	.02	.30	.04	.84	.25	<.001	.37	<.001	10,480	10,491

Note. AIC = Akaike information criterion; ATS = attitudes toward science (parental mean score); BIC = Bayesian information criterion; DV = systematic exploration; Goal = whether gear engaged with during exploration was connected to one of three gears that activated exhibit goal objects; No PT = No parental talk during time interval; PCI = parent–child interaction style; Time = time interval during exploratory play.

TABLE 15

Significant Results (*p*-Values) for Lag, Concurrent, and Reactive Models for the Relation Between Resolute Behavior and Children's Talk About Actions and Exhibits

		Children's		Children's Talk			
Model	**Time**	**Age**	**Gender**	**Actions/Exhibit**	**No Talk**	**AIC**	**BIC**
Lag	.18	<.001	.24	<.001	.15	7,269	7,279
Concurrent	.17	.001	.58	.46	.46	6,974	6,985
Reactive	.65	<.001	.28	.07	.75	7,167	7,177

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; Time = time interval during exploratory play.

TABLE 16

CORRELATION MATRIX AMONG THE SIX OUTCOME MEASURE VALUES FOR USE IN THE PRINCIPAL COMPONENTS ANALYSIS

			Generalization		
Outcome Measure	**Mechanism**	**Reconstruction**	**Fluency**	**Originality**	**Elaboration**
Color memory	.02	.15	.07	.10	.07
	p = .37	*p* = .004	*p* = .10	*p* = .04	*p* = .09
Mechanism		.19	.15	.14	.04
		p < .001	*p* = .003	*p* = .006	*p* = .22
Reconstruction			.22	.14	.17
			p < .001	*p* = .006	*p* = .001
Generalization Fluency				.48	.11
				p < .001	*p* = .03
Originality					.22
					p < .001

Note. Elaboration was operationalized as off-base constructions that did not involve causal mechanisms.

TABLE 17

Pattern Matrix (Loadings) of the Two Components Extracted From Principal Component Analysis

Task	Component 1	Component 2
Color memory	−.26	.85
Mechanism	.44	.02
Reconstruction	.22	.57
Generalization		
Fluency	.82	−.03
Originality	.79	.02
Elaboration	.19	.43